EXPERIMENTAL INVESTIGATION OF RIVER SEDIMENTATION

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by

Mashiane Samuel Dipela

Final Report submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mashiane Samuel Dipela

ABSTRACT

Predictions of total bed material load for investigation of river sedimentation using selected empirical equations were made based on laboratory data. Data were obtained through observations made from conducting experiments in the hydraulic laboratory using a mobile flume and visualization tank. The experiments are categorized under two alignment namely the straight channel and full curved channel with different discharge. Experimental data covers flow discharges of 1.2 l/s,1.6l/s,2.15l/s and 4.1l/s, average flow depths of 0.08m and median sediment sizes of 0.25mm.The equations use in the evaluation are Ackers and White, DuBoys, Shield's, Schoklitsch's and Meyer-Peter's. The selection was based on the performance of these equations by past investigators who showed good agreement between observed and calculated transport rates. The accuracy and the reliability of these formulas are verified.

One of the other objectives of the project is to observe and analyze the changes in the morphology of the river by introducing the structure in the channel such as groin. The groin used is made of wood and the changes that were observed where measured and indicated as form of graphs of how the geometry of the channel alternate. The experiments where carried by varying certain parameters while keeping the width of the channel and the size of the groin constant and the graphical presentation are discussed.. Dimension, pattern, and profile of the river and its velocity are the essential properties to focus on in this project in order to be able to understand the driving force of the mechanism of the natural rivers.

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CHAPTER 1

INTRODUCTION

Since the continents formed millions of years ago, rivers have been important geologic forces as conveyors of water and sediment. The rise of human civilization is intimately linked to rivers for access to drinking water, irrigation, transportation, and fisheries. People have irrevocably altered the landscape by maintaining rivers for navigation, constructing irrigation works, and building dams for hydroelectric power generation. Scientists study river systems as they are important to the flow of fresh water over wide areas of land and across continents. Rivers are also an important part of sensitive habitats, especially wetlands. The study of rivers is necessary to ensure the protection of ecologically important habitats. Natural Rivers are self regulated systems that are responsible for the erosion transport and deposition of sediments. As a result over periods of the geological time; landforms evolve as rivers curve their valleys and create their flood plains. Rivers that are undergoing erosion or deposition will return to their stable condition in response to the negative feedback mechanism, by adjusting their morphology to transmit the sediment load delivered from upstream. Provided environmental condition remain constant, no tectonic activity, land use or climate change; rivers will eventually remove all the readily transportable material from the river bed.

Total bed material load is a measure of rate of transport of sediments in a river. Predictions on the rate of transport of sediments are required for basis of design of hydraulic structures, managing scour related problems and others. The transportation of sediments is governed by several interrelated parameters that contribute to the complexity of the phenomena. A large number of sediment transport equations have been developed in the past by several investigators employing several theoretical approaches. Equations derived empirically and through laboratory measurements may predict well for laboratory concentrations only. This is because the conditions in the laboratory are more controlled and certain parameters are kept constant. Unlike natural channels the parameters change with time, so is the amount of sediment discharge. The derived equations when tested on field data may produce drastic values compared to the observed or measured values. The predictors derived experimentally or empirically may either over- estimate or under-estimate the total sediment concentrations in natural channels.

The formulation in predicting sediment discharge has started since 1879 by Du Boys who introduced the tractive force approach in his bed load formula. Work on quantification of fine-grained sediment movement based on the time-dependent, advection-dispersion equation was presented by Scarlatos and Li (1992). Yang and Molinas (1996) modified his unit stream power formula for the computation of total bed-material load in a sediment-laden river with a high concentration of fine suspended materials. Molinas showed that the relationships derived from flume experiments with shallow flows cannot be universally applied to large rivers with deep flows. His analysis indicated that the commonly used Engelund and Hansen, Ackers and White and Yang equations which were developed using flume experiments are not applicable for large rivers with flow depths and Reynolds numbers up to 100 times larger than those found in flumes. Modeling of non-uniform-sediment fluvial process based on a multimode characteristics method was developed by Yehetal.(1995) which provides information on the formation of flow field, bed topography and bed material composition. The most recent study on the fractional transport rates of non-uniform sediments was conducted by Wu et al

The preservation of rivers against the erosion and devastation caused by water flow through using groins is considered as one of the most common methods in river engineering. Changing the hydraulic conditions and creating laminar flow. The groins decrease the erosion power of water and its ability to carry the sediments and set the ground for sedimentation and stabilizing the banks of the rivers. Therefore the study of introduction of groins is essential in understanding and altering the river structures.This chapter introduces the reader to the continuing research project carried out by the student. It is required of the author to conduct an intensive research with regards to quantifying the impact of sediment feeding in rivers by conducting experiments in the hydraulic laboratory using table flume on sediment transportation. It is also required for the author to investigate by observation the introduction of structures in rivers.

1.1 Background Of Study

In industrial countries, large rivers are often trained to a large extent, to maintain services such as navigation, hydropower generation and flood defense. Most of the methods which are used in the stabilization of rivers lead to morphological disorders that lower the ecological value of habitats. Many rivers have been undergoing ecological and hydraulic restoration measures, especially in reaches bypassed by hydraulic structures. The measures range from optimizing the compensation discharges, to reconnecting the river in water bodies, and artificial sediment feeding. Sediment feeding measures may follow different protocols, according to the material sources (banks, alluvial terraces, excavations due to works, gravel mining, etc.) and the way of injection (introduction from bank, recreation of artificial bed forms, etc.). The efficiency and potential negative effects must be accessed through studies and local tests before large-scale operations, and by detailed monitoring after such operations.

One of the aspects to understand the behavior of rivers is assess river sedimentation and how meanders form and migrate. River meandering processes have been a main focus of geomorphic research for many decades, and much progress has been made in developing flow theory, predicting bed morphology, and predicting plan form evolution in bends. Yet we still do not have a complete understanding of how interactions among flow, bed morphology, and channel plan form combine to produce complex patterns of meandering, such as compound meander loops, or loops with multiple arcs of curvature. Most research of meanders has been confined to flume studies, computer models, or simple field configurations, and the paucity of field based studies of compound loops is surprising. One aspect is also to consider is how rivers structures such as groins are important elements of most river system, being points at which rapid changes in flow, sediments discharge and hydraulic geometry must be accommodated.

1.2 Problem Statement

Rivers are important to humans because they supply fresh drinking water, serve as home for important fisheries, provide transportation routes, and are the source for irrigation water and hydroelectric power (Ackers, 1992). Humans have used rivers since the beginning of civilization.

There is increasing uncertainty regarding the possible effects of global climate change on worldwide patterns of rainfall and snowfall. Hence, the conservation and preservation of rivers and their corridors have become even more important.

Therefore investigation on the morphology of rivers is required. Therefore one has to understand that the combination river sedimentation in a river's channel and on its floodplain works to produce the characteristic features of that river; the three major influences on patterns river sedimentation are geology, the type of sediment that is present, and the amount of water available. River features are also affected by the flow rate and the size and duration of floods. Understanding and quantifying the impact of sediment feeding in rivers, how they are classified and behave according to the heterogeneity of the river lead to a step closer in river conservation and depict what measures to take.

1.3 Objectives

- The main research objectives were to better understand the geometry, depositional and sediment processes
- Conduct experiments using a table flume on a straight and meander channel assimilations
- Calculate the concentration of sediments transported during experiments
- Investigate the introduction of structures in rivers

1.4 Scope Of Study

The scope of study comprises of experimental investigation, development of a laboratory model. The laboratory model will be used to conduct experiments. Basically here, the main aim is acquaint the student with several aspects in hydraulic changes of rivers. This can only be achieved through several Laboratory experiments of which will be tackled in the upcoming weeks, as of now. A good knowledge and proper understanding of previous cases studies is essential.

1.4.1 Laboratory Experiments

The laboratory experiments will be conducted using sediments (sand). Observing and analyzing the behavior of sediments according to different sizes. Different size exploits different properties. The apparatus utilized will be flume, point gauge, ruler, stopwatch and camera. The experiments are conducted in the hydraulic lab.

CHAPTER 2

2. LITERATURE REVIEW AND THEORY

This chapter summarizes the literature review and theory involved for carrying out the project. Important aspects of the project are briefly explained, these include, theory on meandering and sediment transportation and types of groins used in rivers.

2.1 Incipient Motion

Incipient motion is an essential aspect to consider in the study of sediment transport, channel degradation, and stable channel design. Incipient motion is defined as the initial flow conditions sediment will begin to move (Yang, 1996). The initial flow conditions are different from each investigator, therefore there are general concepts leading to motion criteria. To understand incipient motion according to different criteria one has to understand the forces acting on the sediment (see figure below)

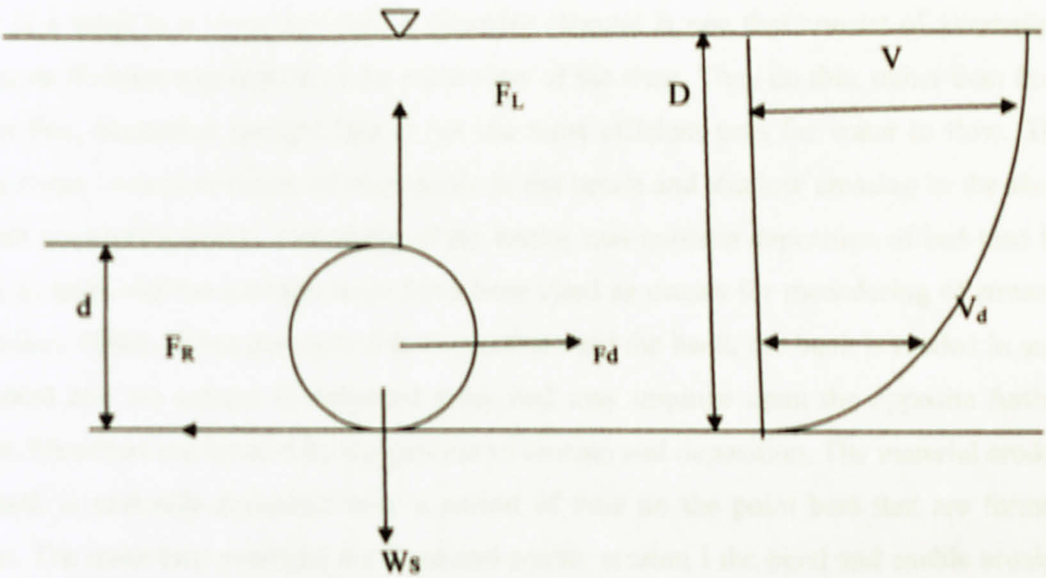


Figure 1: Forces acting on Sediment in an open Channel

F_L = Lift Force, F_D = Drag Force, F_R = Frictional Force W_S = Weight Submerged

A sediment particle is at state of incipient motion when one of the following conditions is satisfied, $F_L = W_S$ $F_R = F_D$ $M_O = M_R$ where M_O is the overturning moment due to F_D and F_R, and M_R is the resisting moment due to F_L and W_S. For most natural rivers, the channel slope are small enough that the component of the gravitational forces in the direction of flow can be neglected compared with other forces acting on the spherical moment. From research of different criteria's, most incipient motion criteria are derived from either a shear stress or a velocity approach.

2.2 Meandering River

Meandering rivers are characterized by progressive growth and migration of their bends, which results from the combination of bank erosion and opposite bank accre-tion. In most physics-based meander migration models the main river channel shift is computed as a function of the flow velocity and depth near the eroding bank. Bend mi-gration is obtained due to a space lag between the maximum near-bank flow velocity and the bend apex (Sellin, Ervine and Willetts, 1993).

A meander is a bend in a river therefore a meander channel is one that consist of alternating bends giving an S-shape appearance to the plain view of the river. They do this, rather than flow in a straight line, because a straight line is not the most efficient path for water to flow. The meandering rivers consist of series of deep pools in the bends and shallow crossing in the short straight reach connecting bends. Sloughing of the banks, non uniform deposition of bed load by debris such as trees and the carioles force have been cited as causes for meandering of streams (Kawai& Julien. 1996). When the current is directed toward the bank, the bank is eroded in area if impingement and the current is deflected away and may impinge upon the opposite further downstream. Meanders are formed by the process of erosion and deposition. The material eroded from the bank is normally deposited over a period of time on the point bars that are formed downstream. The point bars constrict the bend and enable erosion I the bend and enable erosion in the bend to continue accounting for the lateral and longitudinal meandering stream. As rivers flow, they carry sediment.

Energy is needed to carry this sediment. But if the river has some spare energy, it can erode or wear away its bed, banks and other parts of the river. Most erosion normally occurs on the outside bend of a meander. This is because the water on the outside bend travels with greater velocity than the one on the inside of the bend. The inside of the bend is termed point bars and the outside cut banks. Point bars is where slow moving water is depositing the fine sediments and cut banks is where faster moving water erodes the bank. Often there is a steep side to the outside river bank. The bank may overhang. There may be pieces of sediment in the river. As erosion and deposition occurs the meander migrate and get bigger.

Figure 2: River Meandering

Occasionally, a river may take a shortcut between loops of its path. In the diagram, if A and C touched one another, the river would cut directly from A to C, leaving the loop below this shortcut as an oxbow lake.

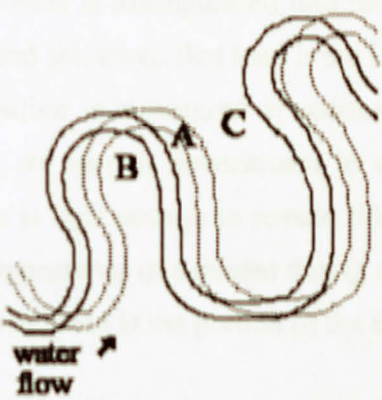


Figure3: River Meandering indicating the path of oxbow formation

Therefore an oxbow lake is a crescent-shaped lake that is formed when a bend in a river is cut off from the main channel by the forces of erosion. An oxbow lake will slowly be created as soil erodes and re-deposits, changing the river's original course.

2.3 Sediment transportation

Sediment transportation deals with transport of the sediments by the flow of the river. One to understand the mechanism, have to understand the properties of the sediments. Sediments properties of a single particle are important in the field of sediment transport are particle size, shape, density, specific weight and fall velocity (Julien P. Y, 2002). While the properties and behavior of a single particle are of great concern, the greatest interest is in bulk properties. The greatest bulk properties of concern are size distribution, specific weight and size distribution. An important variable used to estimate the resistance to flow and the rate of sediment transport is fall velocity

Sediments are classified as cohesive and non-cohesive. In cohesive sediment, the resistance to erosion depends on the strength of the cohesive bond binding particles .They may become non-cohesive. Cohesive sediment particles react to fluid forces and their movement is affected by the physical properties of the particle such as size, shape and density. For the investigation we only going to consider non cohesive sediment

Stream transportation of sediments is distinguished into the following types suspend load, bed load, traction, dissolved load and salvation. Bed load is the large or heavy sediment particles that travel on the stream bed. Traction is movement of sediments by rolling, sliding or dragging. Salvation is when sediments are carried downstream in a series of short leaps or bounces. Suspended load: sediment that is light enough to remain lifted indefinitely above the bottom by water turbulence; the muddy appearance of a stream during a flood or after a heavy rain is due to a large suspended load. Dissolved load is the portion of the total sediment load in a stream that is carried in solution.

Sediment transport is essential to watershed analysis and the dynamic adjustments of river system resulting from natural causes, the implementation of various water resources development activities and responses to the environmental concerns. The rate of sedimentation or the magnitude of sediment concentration has been assumed to be largely determined by certain variables such as water discharge, velocity, energy gradient, shear stress, relative roughness, etc (Ackers, 1992). These variables are utilized to develop certain relationships that explain the river sedimentation. Sediment transport theories and equations have been developed to discuss and analyze the mechanism of sediment transport and behavior. However this sediment transport equations have certain clause that abide to them, there is no universal equation that is applicable to all conditions. For different conditions different equation is applicable. The best way to choose the equation is to calculate the rate of transport using the selected relationships and compare them the results with field data. Here are some of the equations that were instigated:

- Eistein bed-load function
- Modified Einstein method
- Meyer-peter method
- Toffaletti method
- Streampower method
- Yang and Molinas Method
- Laursen Method
- Colby method
- Etc,

Use Einstein's procedure when dealing with sand-bed, Toffaleti's formula for large sand, Colby (1964) for sand-bed rivers with depth less than 10 feet, yang (1973) for sand-bed laboratory flumes and yang (1984) relationship for transport of gravel when the bed material is between 2 and 10mm.

The types for stream transportation of sediment are bed load, traction, salvation, suspended load and dissolved load. Bed load is the large or heavy sediment particlesthat travel on the stream bed. Traction is movement of sediments by rolling, sliding or dragging. Salvation is when sediments are carried downstream in a series of short leaps or bounces. Suspended load: sediment that is light enough to remain lifted indefinitely above the bottom by water turbulence; the muddy appearance of a stream during a flood or after a heavy rain is due to a large suspended load. Dissolved load is the portion of the total sediment load in a stream that is carried in solution. Bar is a ridge of sediment, usually sand or gravel, deposited in the middle or along the banks of a stream; formed by deposition when a stream's discharge or velocity decreases; stream deposits heavier boulders first and small particles last

Figure 4. Gravel Bars along the Banks and in the Middle of A Stream

Placer deposits: when the heavy sediment is concentrated in the stream where the velocity of the water is high enough to carry away lighter materials but not the heavy sediment. Placer deposits were found in streams where the running water has mechanically concentrated heavy sediment. Braided stream is a stream that flows in a network of many interconnected rivulets around numerous bars. A stream tends to become braided when it is heavily loaded with sediment and has banks that are easily eroded.

Figure 5 . A Braided River

2.3.1 Sediment transport equations

1.Eintein' Approach (Yang, 1996)

Einstein *(1* 950) expressed the resistance due to grain roughness by:

$$\frac{V}{U_*'} = 5.75 \log\left(12.27\frac{R'}{k_s}x\right) \tag{1}$$

where *U* = shear velocity due to skin friction or grain roughness = ***(gR s)"'*,**
R' = hydraulic radius due to skin friction,
***k*,** = equivalent grain roughness = *dA5*,
x = a function of ***k*,@,** and
6 = boundary layer thickness, which can be expressed as:

$$\delta = \frac{11.6\nu}{U_*'} \tag{1a}$$

2.3.2 Engelund and Hansen's Method (Yang , 1996)

Engelund and Hansen (1 966) expressed the energy loss or frictional slope due to bed form as:

$$S'' = \frac{\Delta H''}{L} = \frac{q^2}{2gL}\left(\frac{1}{D-\frac{1}{2}A_m} - \frac{1}{D+\frac{1}{2}A_m}\right) = \frac{V^2}{2gL}\left(\frac{A_m}{D}\right)^2$$

.. (2)

Where AH" = frictional loss due to bed forms of wave length L,
q = flow discharge per unit width,
D = mean depth, and
A = amplitude of sand waves.
The total shear stress can also be expressed as:

$$\tau = \gamma R (S' + S'')$$

(2a)

Substituting equation (3.135) for **S** " into equation (3.137) and assuming R = ***D*** for a wide open channel.subtitide equation 1 into 2 then we we get the following:

$$\frac{\tau}{\gamma D} = \frac{\tau'}{\gamma D} + \frac{V^2}{2gL}\left(\frac{A_m}{D}\right)^2$$

(2b)

And

$$\theta = \frac{DS}{[(\rho_s/\rho)-1]d}$$

(2c)

Let

$$\theta' = \frac{D'S}{[(\rho_s/\rho)-1]d}$$

(2d)

where *p*, and p = densities of sediment and water, respectively,
D and *D'* = water depth and corresponding depth due to grain roughness, respectively,
d = sediment particle size, and
Fr = Froude number

2.3.3 Van Rijn formula (Hossain, (1987))

Van Rijn (1984) developed an analytical relationship for sediment load transport in terms of the saltation height, particle velocity and bed load concentration. The transport equation can be expressed in a simplified form when only the mean velocity, flow depth and particle size are known was given as:

$$\frac{q_b}{ud} = 0.005\left(\frac{u - u_{cr}}{[(s-1)gD_{50}]^{0.5}}\right)^{2.4}\left(\frac{D_{50}}{d}\right)^{1.2} \tag{3}$$

$$\frac{q_s}{ud} = 0.012\left(\frac{u - u_{cr}}{[(s-1)gD_{50}]^{0.5}}\right)^{2.4}\left(\frac{D_{50}}{d}\right)(D_*)^{-0.6} \tag{3a}$$

$$u_{cr} = 0.19(D_{50})^{0.1}\log\left(\frac{12R_b}{3D_{90}}\right) \quad \text{for } 0.1 \le D \le 0.5 \text{ mm} \tag{3b}$$

$$u_{cr} = 8.5(D_{50})^{0.6}\log\left(\frac{12R_b}{3D_{90}}\right) \quad \text{for } 0.5 \le D \le 2.0 \text{ mm} \tag{3c}$$

2.3.4 Ackers-White equation (Yang , 1996)

Ackers & White (1973) applied the advantages of dimensional analysis technique, but Used the physical arguments to express the mobility and transport rate of sediment in terms of some dimensionless parameters. The mobility number is denoted by Fgr, and a general definition is:

$$F_{gr} = V_*^n / \sqrt{gD(s-1)} \left[V / \sqrt{32} \log(\alpha \, d/D) \right]^{1-n}$$

Dimensionless grain diameter is applicable to coarse, transitional and fine sediments and is the cube root of the ratio of immersed weight to viscous forces, i.e.

$$D_{gr} = D\left[g(s-1)/\upsilon^2\right]^{1/3} \tag{4}$$

A general dimensionless sediment transport function can be expressed as:

$$G_{gr} = f(F_{gr}, D_{gr})$$

$$G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right)^m \tag{4.1}$$

in which $G_{gr} = \frac{X d}{s D}\left(\frac{F_{gr}}{A} - 1\right)^n$ and A, C, m and n can be obtained as follows:

$$n = 1.00 - 0.56\log D_{gr}$$

$$A = 0.23/\sqrt{D_{gr}} + 0.14$$

$$m = 9.66/D_{gr} + 1.34 \text{ and}$$

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \tag{4.2}$$

2.3.5. Shield' Approach equation.

$$(q_b \, \gamma s/q \, \gamma s) = 10(\tau-\tau_c)/(\gamma s-\gamma)d_{50} \tag{5}$$

q = bed load and water discharge per unit channel width respectively;
$\tau = \gamma DS$

γ, γ_s = specific weights of water and sediments,respectively

2.3.6. DuBoys' Approach equation (Yang , 1996)

DuBoys assumed that sediment particles move in layers along the bed. The layers move because of tractive forces acting along the bed. The thickness of each layer is ε. Under equilibrium conditions, the tractive forces should be balanced by the total resistance force between these layers

Where $\tau = \gamma DS = C_f m\varepsilon (\gamma_s - \gamma)$ (6)

C_f = friction factor

m= total number of layers

ε=layer thickness

D= water depth

S = slope

γ ,γ_s = specific weights of water and sediments, respectively

if velocities varies linearly between the first and the m-layers, the total bed- load discharge by volume per unit channel width is

$$q_b = \varepsilon V_s m(m-1)/2 \quad (6a)$$

$$\tau_c = C_f m\varepsilon (\gamma_s - \gamma) \quad (6b)$$

And $m = \tau/\tau_c$ (6c)

Where τ_c = critical tractive force along the bed.

From equation (6a) and (6c)

$$q_b = \varepsilon V_s \tau(\tau - \tau_c)/ 2 \tau_c^{\ 2}$$

$$= K\tau(\tau - \tau_c) \quad (6d)$$

The coefficient K in Eq.(6d) is related to the characteristics of the sediment particles.

$$K = 0.173/d^{3/4} \quad (6e)$$

2.4 BED FORMS

Bed forms are defined as plain bordering a river, formed by the deposition of material eroded from areas of higher elevation. There exist a strong interrelationship between bed configuration resistance to flow and the rate of sediment transport (Gill,1972). Therefore understanding bed forms one gain the knowledge of the characteristics of bed forms are important in alluvial streams for determining channel resistance, flow depth, and for use in calculating sediment transport. Bed forms may also be preserved as primary sedimentary structures which potentially contain a large amount of information on the nature of the generating flow and on the type of depositional environment present when the sediment was deposited.

Plane bed, Ripples, bars, dunes, transition, antidunes, chutes and pools are different names used to classify bed forms according to their size and shape. The size of bed forms are determined by the rate of velocity (indicated by the figure below)

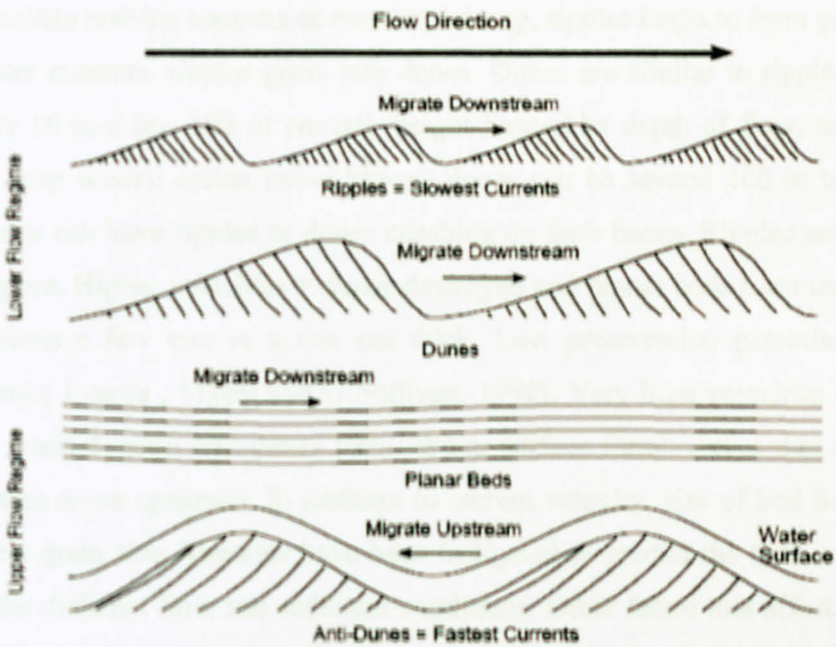


Figure 6: Bed forms

From the figure above one can see that the flow in sand-bed channels can be classified into lower and upper flow regimes, with a transition in between. The bed forms associated with these flow regimes are as follows:

1. Lower flow regime:
   - Ripples
   - Dunes

2. Transition zone: bed configuration range from dunes to plane beds or to antitudes.
3. Upper flow regime:
   - Plane bed with sediments movements;
   - Antidunes;
   - Breaking antidunes;
   - Standing waves;
   - Chutes and pools

At lowest velocities nothing happens as current picks up, ripples begin to form generally 0.5 to 3 cm tall. In faster currents, ripples grow into dunes. Dunes are similar to ripples, but larger. In water, typically 10 to a few 10's of cm tall (height limited by depth of flow, so can be several meters tall in deep water); eolian (wind-blown) dunes can be several 100 m tall. Under some conditions, dunes can have ripples or dunes climbing up their backs. Ripples and dunes form in lower flow regime. Higher velocities = dunes destroyed and planar beds form may have internal planar laminations a few mm to a few cm thick. Low preservation potential due to highly energetic setting (Lyness , Myers and O'Sullivan, 1998). Very high velocities (stream running down a steep sandy beach): anti-dunes form. Water surface forms waves that move upstream, and so ant-idunes move upstream. In addition to current velocity, size of bed forms depends on water depth and grain size. Theories have been instigated to predict the type and dimension of bed forms under different flow and sediment conditions. Other factor that affects bed forms and resistance to flow are water depth, bed material gradation, fall velocity of sediments particles, channel cross-sectional shape, fluid density, fine material concentration, bed material size, fall velocity of sediment particles and see page force.

The total roughness's of the alluvial channels is made or consist of two parts, namely grain roughness and roughness due to bed forms. Form roughness poses a major problem in the study of the study of hydraulics hence essential to study Listed below are some of the equations used to predict the variation of form roughness.

2.5 Groins in rivers

A groin is rigid hydraulic structures built from an ocean shore or from a bank (in rivers) that interrupts water flow and limits the movement of sediment. In a river, groins prevent erosion and ice-jamming, which in turn aids navigation. The areas between groups of groins are groins fields. Groins are generally made of wood, concrete, or rock piles, and placed in groups. Groins are common and require little maintenance (Garde, 1961). The groins decrease the erosion power of water and its ability to carry the sediments and set the ground for sedimentation and stabilizing the banks of the rivers. One of the important issues in designing groins is studying scoring and determining the scoring depth in the head land of the groins. One of the effective parameters on the scoring depth around the groins is the angle alternation in river bend.

They are man-made structures designed to trap sand as it is moved down the beach by the long-shore drift. As the long-shore drift current approaches the groin, it is forced to slow down and change direction. This chance in velocity causes sand suspended in the current to be deposited on the up-drift side of the groin. As the current then continues around the groin, it becomes turbulent and actually contributes to erosion on the down-drift side of the groin. River groins are often constructed nearly perpendicular to the riverbanks, beginning at a riverbank with a root and ending at the regulation line with a head. They maintain a channel to prevent ice jamming, and more generally improve navigation and control over lateral erosion, that would form from meanders. Groynes have a major impact on the river morphology: they cause autonomous degradation of the river. They are also used around bridges to prevent bridge scour (Ghodsian,M, Tehrani,A,2001)

CHAPTER 3

Experimental Setup & Procedures

3.1 MOBILE BED AND FLOW VISUALISATION TANK

The flume is located at Hydraulic Lab of Department Civil Engineering, Universiti Teknologi Petronas, Malaysia. This apparatus is operated with the water pumped from the sump in the downstream tank to the base of the upstream tank where it rises through a perforated baffle plate to distribute the flow evenly before it enters the working section of the tank (see Figure A1). A shallow channel, with approximately dimensions 4000 mm long, 600 mm wide and 150 mm deep with a slope of 0.0034, provides the working section for the experiment. Most experiment requires a plane bed with a small frictional resistance in the working section. A plain glass sheet (two sheets on the 4 m version) is supplied for this purpose, with supports having leveling screws which should be adjusted until the sheet lies in a horizontal plane. The plain sheet must be wedged along its sides to prevent it being lifted by hydraulic up thrust. The depth of flow in the working section is controlled by adjusting the height of a weir at the downstream end of the working section [Armfield, 2005].

Therefore, it is a versatile apparatus for teaching, project and research work. It simulates properties of rivers that need to be studied. This apparatus gives a flow pattern which is the name given to a description of the main features of a fluid flow within a stated zone. A complete flow pattern gives information throughout the zone about the velocity field, turbulence levels, pressure variation and any vibration of solid boundaries.
The tank may be used in two principal fields of study.

- Hydraulic modeling of mobile bed situations such as water courses or civil engineering structures
- Two-dimensional flow visualization using, for example, the Ahlborn dust indicator technique.

Figure7. Mobile Bed Tank

This apparatus is utilized in this project t o achieve the aimed objectives.

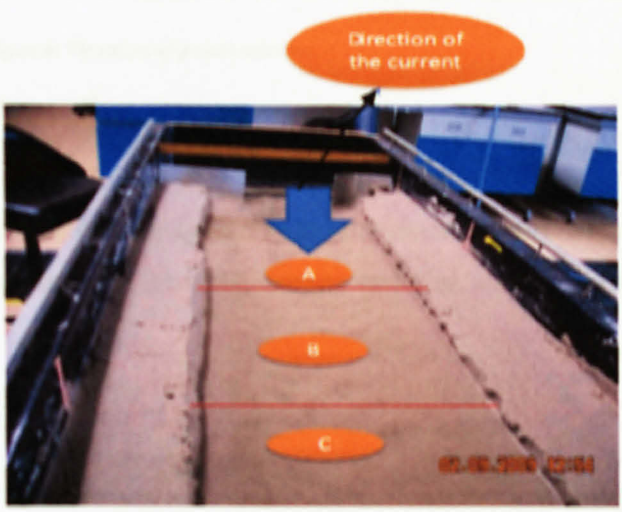


Figure7a. Mobile bed sections

Sections are divided into the following length:

- Section A from 0→580mm
- Section B from 580 → 830mm
- Section C from 830 →1580mm

3.2 Experimental Procedures

This section elaborates on the procedures and steps that where followed in order to archive the main aimed objectives of the project. The figure below indicate the sequence at which the experiments where planned and carried-out

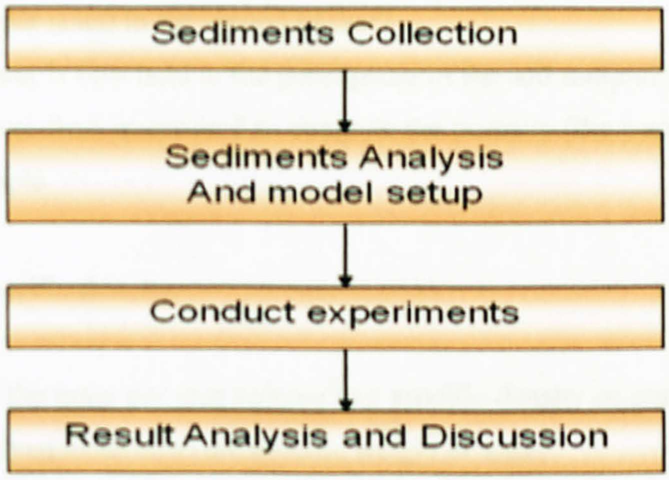


Figure 8: Flowchart of project activities

3.2.1 Sediments Properties

One of the primary tasks in the investigation is to understand the properties of the sediments as it is essential to sediments transport. Porosity, density and size were determined by conducting the following procedures.

3.2.1.1 Porosity

Soils are made of particles of different types and sizes. The space between particles is called pore space. Pore space determines the amount of water that a given volume of soil can hold. Porosity is the percentage of the total volume of soil that consists of pore space. It is determined by following procedure:

1. Fill one beaker, up to the 48 ml mark, with dry soil or sand. Place it on a table or flat workspace.
2. Fill the other beaker, up to the 50 ml mark, with water.
3. Slowly pour the water from the second beaker into the soil sample. Stop pouring when the water level reaches the top of the soil. The soil has reached saturation and cannot hold any more water.
4. How much water is left in the second beaker?
5. How much water is now held in the pore spaces of the soil sample?
6. Use your answer from question 5 to compute the porosity (the percentage of pore space) of the soil sample.

3.2.1.2 Density & Specific density

Density is defined as the mass per unit volume and specific density or gravity is the ratio of the specific weight of a given material to the specific weight of water.

Procedure:

1. Weigh the material.
2. Pour a marked volume of water in the measuring cylinder.
3. Get volume of the weighed material by pouring it in measuring cylinder and recording the volume of the water displaced.
4. Compute density (density= m/v).
5. Compute relative density by dividing the answer in step 5 with density of water.

3.2.1.3 Size

Size is the basic and most readily measurable property of sediments. Size has been found to sufficiently describe the physical property of a sediment particle for many practical purposes. Sieve Analysis is a method used to obtain the sediment size. The properties are analyzed by grading them using a shaker (shown in figure 9).

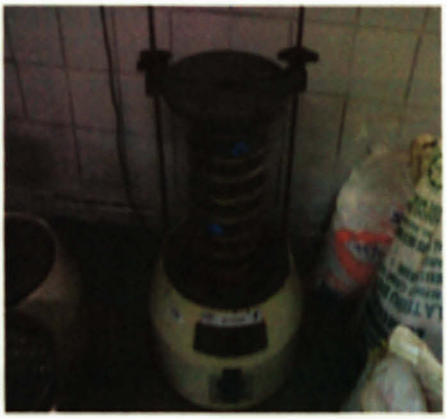


Figure 9: Shaker

3.2.2 Model Setup

The flume was used to model the river that need to study. Various river models with different width, depth and curvature have been and will be modeled using the flume. The other factor, different discharge and different sediment size as well included in this study. The 2 models simulated in this project are the straight and the full curved channel. Figure 9, 10 and 11 indicate the types and set up if the channel used. After modeling, next step is measured the depth of bed material, before and after water flow. Then input it into Arc View. For accurate result, Arc View result will be compared with the theory to obtain the discharge of total sediment.

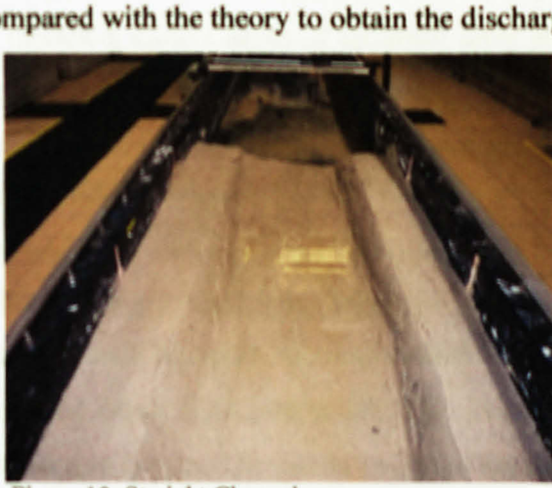


Figure 10: Straight Channel


Figure 11: Curved Channel


Figure 12: Straight Channel

For the curved channel:

λ=meander length =12.75cm

R= radius of the meander = 14.5cm

3.2.3Arc-View

An arc-view is geographic information system (GIS) software for visualizing, managing, creating, and analyzing geographic data. Using Arc-View, you can understand the geographic context of your data, allowing you to see relationships and identify patterns in new ways (DHI, 2002). To build Arc view modeled, collect depth of sediment layer at the bed after allowing the water to flow, for each experiment the scale was 100 mm x 30 mm for every depth of sediment collected therefore, it can simulate the geometry of the river and its properties. Utilizing the software the real field data of the experiment can be approximately obtained. Accuracy of the results can be achieved by taking as many points as possible. The height of the sediments was collected at intervals of 30mm for the width and 30mm for the length until 600mm and then 100mm till the end of the channel to build Arc view modeled. The alteration of sediment transport height occurs along the whole 1960 mm length; therefore the measurement of sediment transport is done just for 1960 mm length. The points collected are then used to simulate the 3D channel on auto-cad after the experiment and then used by arc-view to calculate the area and the volume of the channel.

3.3 Sediments capacity computation experiments

Table 1: Bed-load experiments

Experiment (number)	Alignment (geometry)	Flow rate (lit/s)	Sediment Size(mm)
1	Straight	1.2	0.25
2	Full curved	1.2	
3	Straight	1.6	
4	Full curved	1.6	
5	Straight	2.15	
6	Full Curved	2.15	
7	Full Curved	4.1	

3.4Groin Experiments

These experiments were conducted by constructing a straight river channel with different width and flow rate. The preservation of rivers against the erosion and devastation caused by water flow through using groins is considered as one of the most common methods in river engineering. Changing the hydraulic conditions and creating laminar flow. The groins decrease the erosion power of water and its ability to carry the sediments and set the ground for sedimentation and stabilizing the banks of the rivers. One of the important issues in designing groins is studying scoring and determining the scoring depth in the head land of the groins

5 experiments were conducted on the simulation of a straight channel with the introduction of groins in order to achieve how the limit or control the undesirable changes in course or shape of the river. The flow rates used for the experiments where 1.1lit/sec, 1.7 liters/sec and 2.7liters/sec. Experiments were conducted by constructing a straight channel of a length of 1.5m with a groin placed at 0.5m as indicated in the pictures shown below. The length of the groin is 14cm. Initial condition of the channel were recorded and the experiment was started by opening the channel to

flow for 30min to reach steady before the groin was placed in the channel. After the introduction of the groin the experiment was run for an hour, every 10 minutes the width and depth of the river was recorded from upstream, midstream and downstream. The main of recording the reading for every 10min is to trace the change of its properties how they change with time and how they are affected by different parameters such as discharge and the size of the groin. The graphs indicate how the width changes with time at each section.

The figures below show the alignment of the experiment at the initial condition and after the groin was introduced.

Figure 13: Initial condition

Figure 14: Channel with groin

Table 2: Groin Experiments

Experiment (number)	Channel width (cm)	Flow rate (lit/s)	Alignment	Sediments Size(mm)
1	37	1.1	Straight channel	0.25
2	37	1.7		
3	37	2.7		
4	40	1.1		
5	40	1.7		

CHAPTER 4

4. RESULTS & DISCUSION

4.1Porosity

V= volume

$V_{(solids)} = 48ml$

$V_{(water\ initial)} = 50ml$

$V_{(water\ final)} = 34ml$

Therefore, $V_{(voids)} = 50ml - 34ml = 16ml$

Porosity= $V_{(voids)} / (V_{(voids)} + V_{(solids)}$

$= 16/(16+18)$

$= 0.25$

The value of the measured porosity is found to be 0.25.The test was repeated two more times and the average is close to 0.25

4.2 Density and Specific density

M = mass, V = volume

$M_{(solid)} = 7g$

$V_{initial\ (h20)} = 29ml$

$V_{final\ (h20)} = 31.7ml$

Therefore, volume displaced = 31.7 – 29

$= 2.7ml = V_{(solid)}$

Hence, Density = $M_{(solid)} / V_{(solid)}$

$= 7/2.7$

$= 2.59g/ml$

$= 2590g/ml$

Therefore, Specific Gravity = density solid/density water

= 2590/1000

= 2.59

The test was repeated one more time and gave the value of 2.64

4.3 Size

Table 3: Gradation of soil

Siever Dimension	Self Weight	Self Weight + Aggregate	Aggregate Retained	Percentage Retained	Cumulative Percentage Passing
(mm)	(gr)	(gr)	(gr)	(%)	(%)
4.750	496.5	496.5	0.0	0	100
2.360	458.1	458.7	0.6	0.119976005	99.880
1.180	354.4	356.1	1.7	0.339932014	99.540
0.600	388.5	390.3	1.8	0.359928014	99.180
0.300	357.0	513.2	156.2	31.23375325	67.946
0.212	345.8	496	150.2	30.0339932	37.912
0.150	335.5	425	89.5	17.89642072	20.016
0.063	330.9	426.2	95.3	19.05618876	0.960
0	248.4	253.2	4.8	0.959808038	0.000

Σ = the mass of total sand sieved=500g

The above results yield the following s-curve, where the average size (d_{50}) can be obtained from the graph.

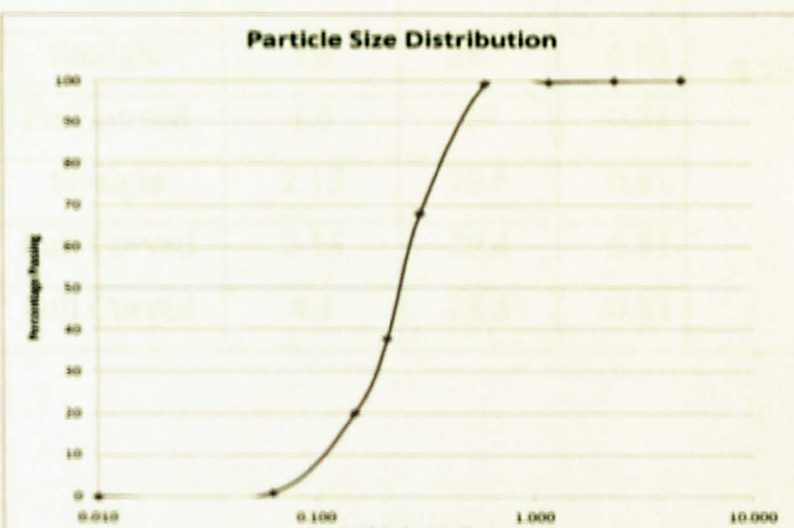


Figure 15: Particle size Distribution of 2.5mm

Determining $\mathbf{D_{50}}$:

$d_{67.946} = 0.3mm$, $d_{37.912} = 0.212$

$\Delta y/\Delta x \longrightarrow (0.3-D_{50})/(D_{50}-0.212) = (67.946-50)/\ (50-37.912)$

Therefore:

$D_{50} = 0.24717993 = 0.25mm$

4.4 Sediments capacity computation

Sediment transport is essential to watershed analysis and the dynamic adjustments of river system resulting from natural causes, the implementation of various water resources development activities and responses to the environmental concerns. Determination of types of loads where investigated and the following conclusion was achieved based on observed following data.

Table 4: Bed-load experiments

Experiment (number)	Alignment (geometry)	Flow rate (lit/s)	Temp.^{0}C	μ (m^3/s) x 10^{-6}	D_{50} (mm)
1	Straight	1.2	29.3	0.82	0.25
2	Full curved	1.2	28	0.87	
3	Straight	1.6	28.5	0.81	
4	Full curved	1.6	29	0.81	
5	Straight	2.15	29.6	0.81	
6	Full Curved	2.15	29.4	0.81	
7	Full Curved	4.1	28.6	0.81	

Figure 16 Experiment 1 after Water Flow

Figure 17. Experiment Suspended Load

From Fig.17 shows that for 0.25 sediment size there is no suspended load in the bottom of glass, therefore investigations of load is mainly based on the bed load sediments. Therefore, the equation employed in this experiment are simply designed for bed load formula, in this case suspended load assumed zero influences discharge of sediment transport. Figure 19 shows preliminary experiment for velocity particle, this experiment using painted sediment, to catch time when sediment moved.

Figure .18 Experiment Particle Velocity

Figure 19. Experiment 2 after Water Flow

Fig.16, 18 and 19 illustrate the modification of sediment transport after water is flowed respectively. Before flowing with water, sediment surface is in plane condition, while after the water is flowed, there are some modification at sediment condition. Fig.13 shows a number of ripples formed.

The three experiments were conducted for an hour. Measured discharge of sediment transport was calculated using the depth differences of bed sand, the depth of sediment layer at the bed was collected, the height of the sediments was collected at intervals of 30mm for the width and

30mm for the length until 600mm then 100mm till the end to build Arc view modeled. The alteration of sediment transport height occurs along the whole 1960 mm length; therefore the measurement of sediment transport is done just for 1960 mm length. The three experiments chosen to be analyzed indicated following geometries (fig 20, 21 and 22) on the computer to which the area and the volume where computed and presented in table 5 and 6 The coordinates of the channels are shown in appendix

Figure 20. Experiment7 (Arc View Model)

Figure.21. Experiment .2 (Arc ViewModel)

Figure 22. Experiment 6 (Arc View)

The computed results of the experiments where compared to few of the theoretical computation using known theoretical formulas. The formulas used to compare the Arc-View results are DuBoy's Formula, Shield's Formula, Schoklitsch's Formula, Meyer-Peter's Formula, Wickers and white and Vijn rign. The results from each experiment are shown in table 3 and 4(appendices B, C, D and E). For incipient motion and resistance to flow experiment, was observed simply theory from Yang's book. Calculation that has been done is calculation for fall velocity, critical tractive force and dimensionless critical velocity. Results for discharge of sediment transport showed.The other experiment is observing the incipient motion and resistance to flow with 0.25 mm sediment size.

7 experiments were conducted using a discharge rate of 1.2; 1.6; 2.15 and 4.1 liters per second. The first six did not indicate great noticeable change except the last one (4.1lit/sec).2 of the experiment where chosen randomly with the last one for analysis. The following parameters where measured. The three experiments (1,6 and 7) chosen for analysis are 1.2 lit/s straight channel, 2.15lit/s straight channel and 4.1 lit/s of a fully curved channel. The calculation are shown in appendix

TABLE.5: RESULTS DISCHARGE OF SEDIMENT TRANSPORT

Exp l/s	Arcview (m^3/s) 10^{-6}	DuBoys' (m^3/s)	Shield's (m^3/s) 10^{-9}	Schoklitsch's (m^3/s) 10^{-9}	Meyer-Peter's (m^3/s) 10^{-6}	Ackers white(m^3/s) 10^{-6}
1	0.5	0.2	2.247	4	1.087	12
6	0.865	0.42	4.270	7	1.1	19
7	1.0772	0.45	9.2	14	1.4	27

TABLE.6 comparison of the results with the arc-view results (% error)

Exp	Arc View	DuBoys'	Shield's	Schoklitsch's	Meyer-Peter's	Ackers white
1	0.5	8.54E+09	62	114927	90	95
6	0.865	1.24E+11	205	946166	58	95
7	1.0772	9.09E+10	567	1760354	38	96

Table 3 shows that in the calculation of sediment discharge there are big gap differences of the total sediment transport result between ArcView calculation, DuBoys' formula, Shield's formula, Schoklitsch's formula, and Meyer-Peter's formula, particularly for DuBoys' formula. Table 5 shows the % error of sediment discharge computation between the practical data (arc-view) with theoretical data. The comparison between the calculated and observed total bed material load is as shown in Table 6.Percentage error is the ratio between the difference of calculated and practical data values to calculated values. The values signify the accuracy of each formula. From the table, among all the five equations used in the evaluation, equation Meyer peters gave the best results but not significant enough to be used in the channel with the same conditions. Schoklitsch's, Shield's and DuBoys equations showed a poor performance on these experiment and Ackers and White equation showed the second best performance. From the table 6, it can be noted that the Ackers-White formula and Duboys seemed to over-predict the values of sediment discharge and the other three equations seemed to under-predict the values of sediment discharge. This indicates that on average the Schoklitsch's, Shield's and DuBoys quations over-predict the values of sediment discharge for the river with aspect to the same condition on the experiment.

4.5 Introduction of groin in the channel

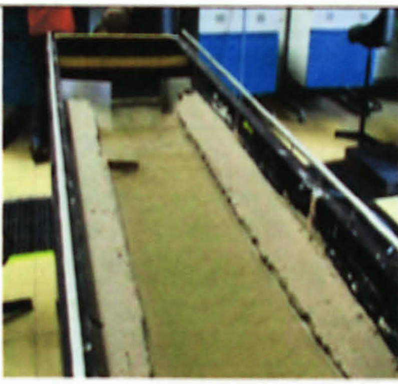
Due to large difference in flow pattern on various positions in bend, the placing groin on different position has significant effect both on topography of bed and scoring peak around it. Figure shown from the following graphs and tables indicate how the groin aid with erosion on the opposite bed and at the same time stabilizing the bed it is connected to. From the data obtain one can deduce that the erosion on the opposite size increases with increasing discharge. The groins effects are affected by the change in the width of the channel deducing that the smaller the groin size the lesser the erosion on the opposite. The way the erosion occurs on the graphs I show that the angle of the way groin can model the morphology of the river. Transversal profiles show that there is a correlation between maximum eroding with and groin size and as the size increases, the rate of erosion increases. There is also a direct correlation, and as the discharge increases crease the scoring depth will increase.

Figure 23: Straight channel with groin

Figure 5.1 indicate that the groin also stabilize the downstream bed it is connected. Therefore the groin can be used to conserve the characteristics of the channel is great detrimental changes occur in the change of river geometry.

4.5.1 Experiment 1 (1.1lit/sec)

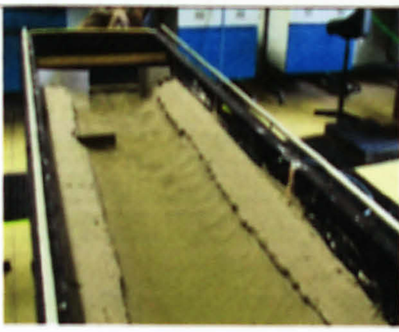
Table 7:Erosion of Bank with time for Experiment 1.1lit/sec for 37cm width channel



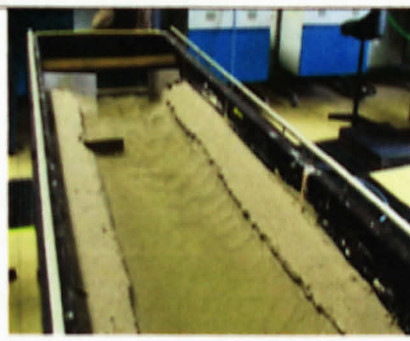
0min

10.53min

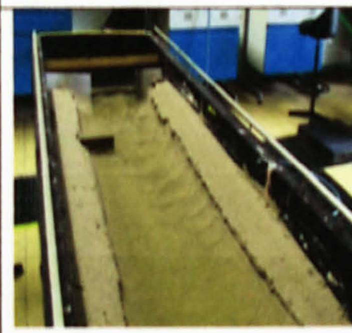
19.53min



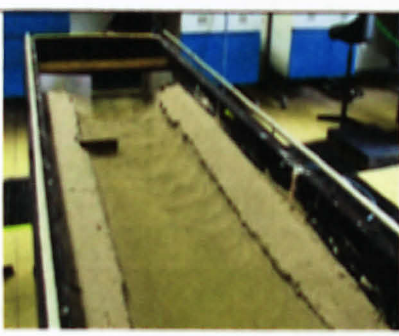
31.49min



41.51min



51.18min



60min

Table 7.1.Conditions of Sand before running

length	depth
410	45mm
920	45mm
1300	36mm

Length	Width
410	37cm
920	37cm
1300	37cm

Table 7.2. Height(mm) of the bank

length	left	Right
410	120	123
920	123	128
1300	123	121

Experiment started at 12:25,for 30min it left t reach steady state

Table 7 .3.Width(cm) during running

time	upstream	groin	middle	downstr
12:55	37	37	37	37
13:05	37.2	39	37	36.5
13:15	36	25	38	36
13:25	37	24	37	38
13:35	36	24.5	37	37
13:45	37	25	37.5	37
13:55	37	26	37	39

Table 7.4.Depth(mm) during running

	80mm			580mm			830mm		
	L	M	R	L	M	R	L	M	R
12:55	89	52	83	86	37	84	87	47	89
13:05	89	53	83	85	36	85	86	48	88
13:15	88	52	89	86	40	84	88	58	85
13:25	87	44	75	86	48	86	87	44	87
13:35	86	45	78	85	45	83	85	36	85
13:45	90	58	90	86	43	85	89	36	84
13:55	86	48	84	82	42	80	82	48	81

1580mm			
R	L	M	R
89	87	28	86
88	87	29	85
85	87	30	84
87	83	29	84
85	83	27	83
84	87	38	86
81	72	31	69

Track of Depth alteration with time

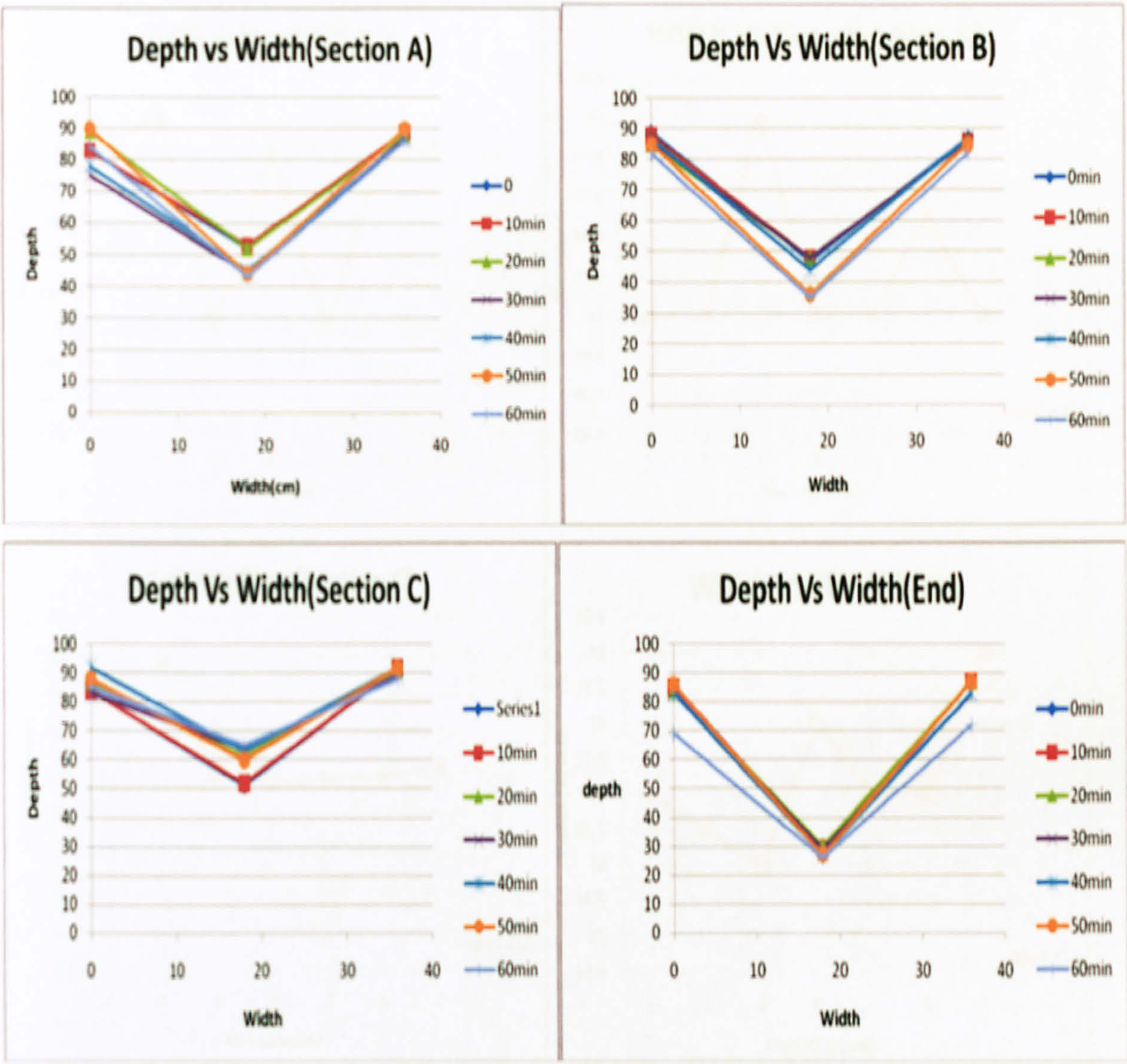


Figure 24: alteration of depth with time (test 1)

Trace of width alteration with time

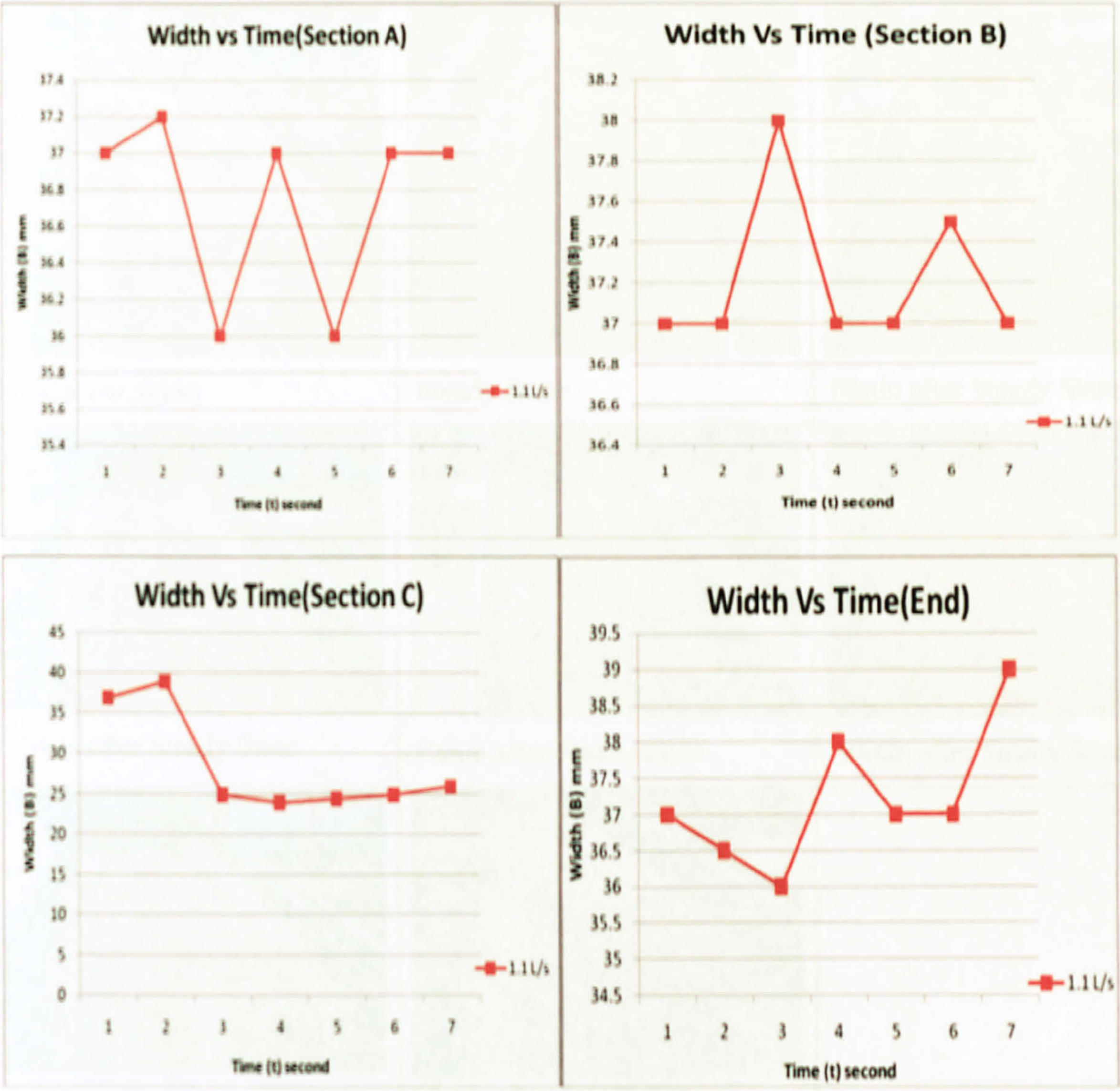


Figure 25: alteration of width with time (test 1)

4.5.2 Experiment 2 (1.71 lit/sec)

Table 8: Erosion of Bank with time for Experiment 1.71lit/sec for 37cm width channel

Initial condition

Steady State

10min after Steady State

20min after Steady State

30min after Steady State

40min after Steady State

50min after Steady State

60min after Steady State

Table 8.1.Conditions of Sand before running

length	depth
320	51mm
750	46mm
1300	38mm

length	Width
320	36cm
750	36cm
1300	36cm

Table 8.2. height of the bank

length	Left(mm)	Right(mm)
320	128	127
750	126	129
1300	116	118

Experiment started at 14:40,for 30min it left t reach steady state

Table 8.3 width(cm) during running

time	upstream	groin	middle	downstr
15:20	40	26.5	38	40
15:30	40	27	39	40
15:40	40	27.5	39	41
15:50	41	28	40	41
16:00	41	30	42	41
16:10	41	30.2	43	41
16:20	41	31	44	42

Table 8.4.Depth during running

	80mm			580mm			830mm		
	L	M	R	L	M	R	L	M	R
15:20	95	56	97	91	46	92	92	51	84
15:30	94	58	94	90	46	93	92	52	84
15:40	96	57	90	94	53	94	91	61	87
15:50	97	50	95	94	50	94	89	64	83
16:00	95	49	90	92	53	91	92	63	92
16:10	97	56	95	95	52	83	92	60	88
16:20	90	55	90	92	56	92	88	65	85

1580mm		
L	M	R
90	30	82
90	30	82
94	32	90
91	25	91
92	30	86
94	36	93
80	82	90

Track of Depth alteration with time

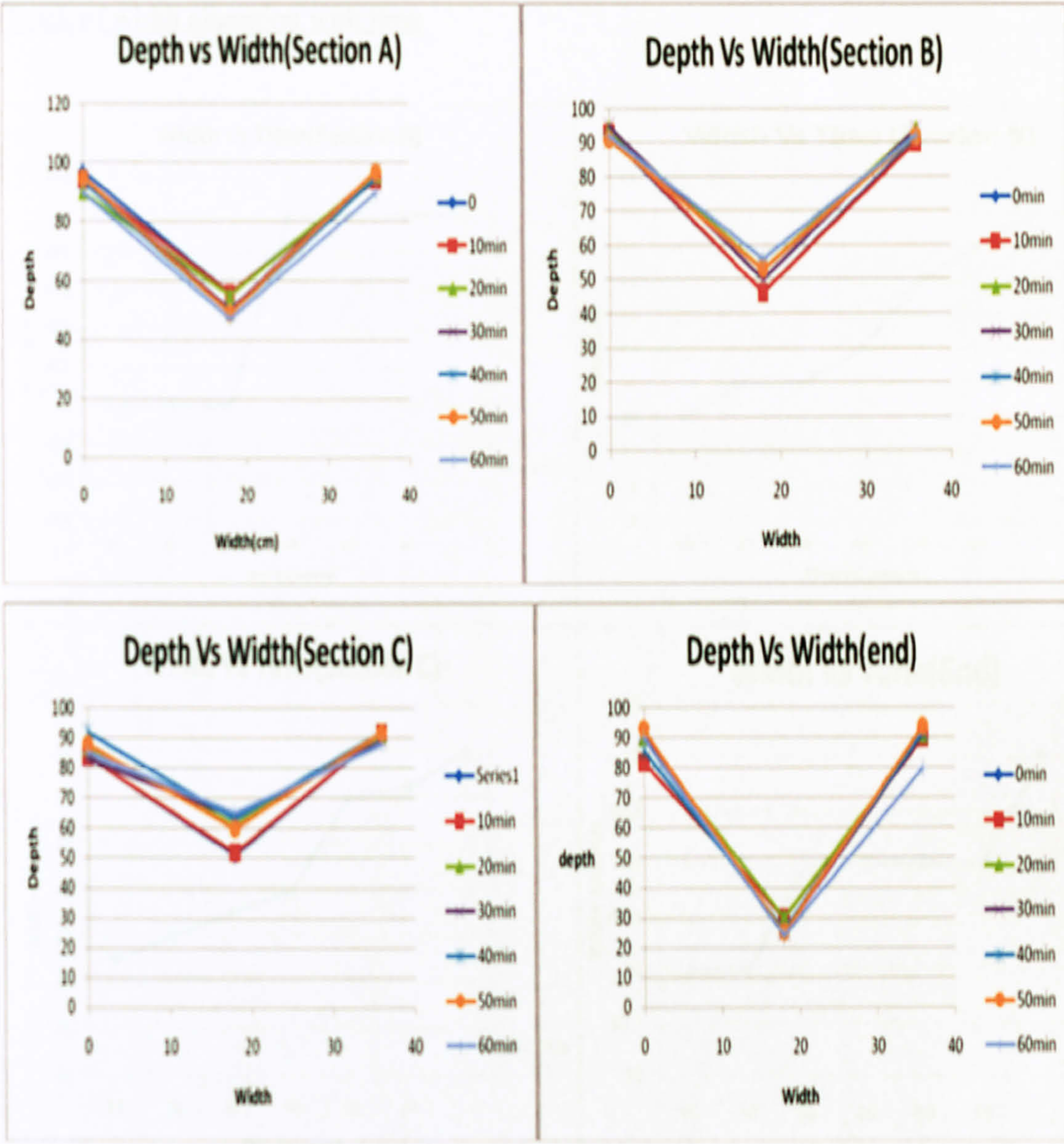


Figure 26: alteration of depth with time (test 2)

Track of width alteration with time

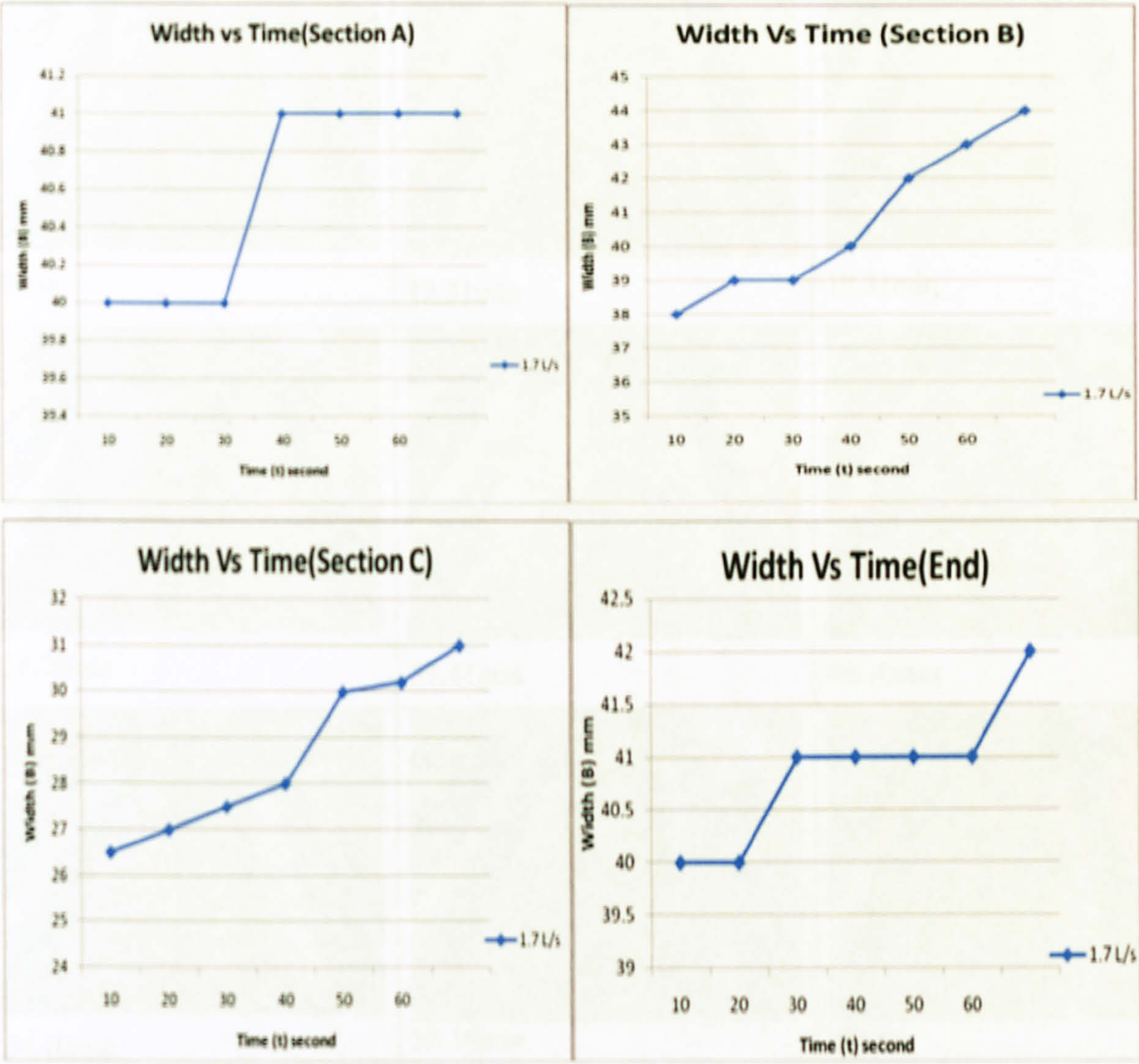
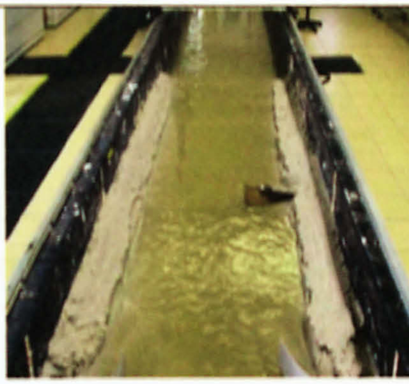
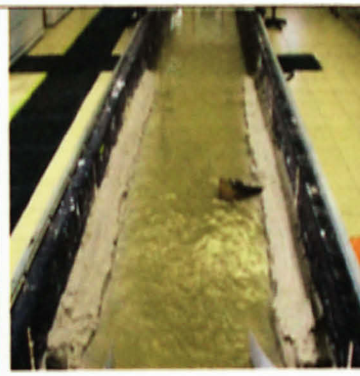


Figure 27: alteration of width with time (test 2)

4.5.3 Experiment3 (2.7lit/sec)

Table 9:Erosion of Bank with time for Experiment 2.7lit/sec for 37cm width channel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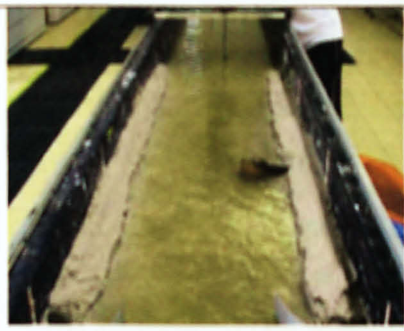
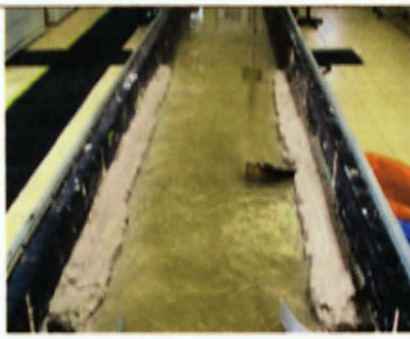
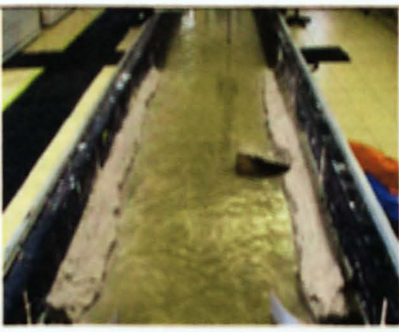
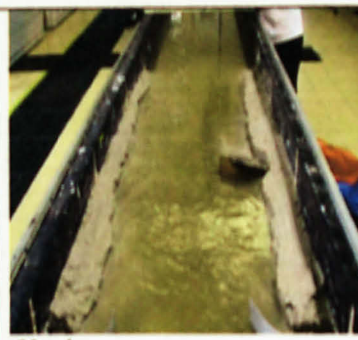
		
28.29min	37.41min	46.10min
		
51.10min	55.10min	60min

<u>Table 9.1Conditions of Sand before running</u>

length	depth
410	55mm
920	40mm
1300	43mm

length	Width
410	37cm
920	37cm
1300	37cm

Table 9.2. height(mm) of the bank

length	left	Right
320	131	126
750	126	128
1300	113	113

Experiment started at 13:00,for 30min it left t reach steady state

Table 9.3.Width(cm) during running

time	upstream	groin	middle	downstr
15:30	42	32	43	48
15:40	43	32.3	46	50
15:50	43	33	46.5	49
16:00	43	33.5	48	49
16:10	43	34	48.6	50
16:20	43	35	49	52

*Table 9.4.*Depth(mm) during running

	80mm			580mm			830mm		
	L	M	R	L	M	R	L	M	R
13:40	90	30	90	90	30	90	38	24	91
13:50	96	34	95	91	36	91	92	42	93
14:00	92	20	96	93	25	92	90	18	91
14:10	94	33	92	95	38	89	88	36	90
14:20	94	34	96	92	38	90	90	30	89
14:30	93	34	93	96	33	96	87	44	90

1580mm		
L	M	R
85	22	84
88	20	87
92	13	91
91	14	93
92	15	90
89	15	91

Track of Depth alteration with time

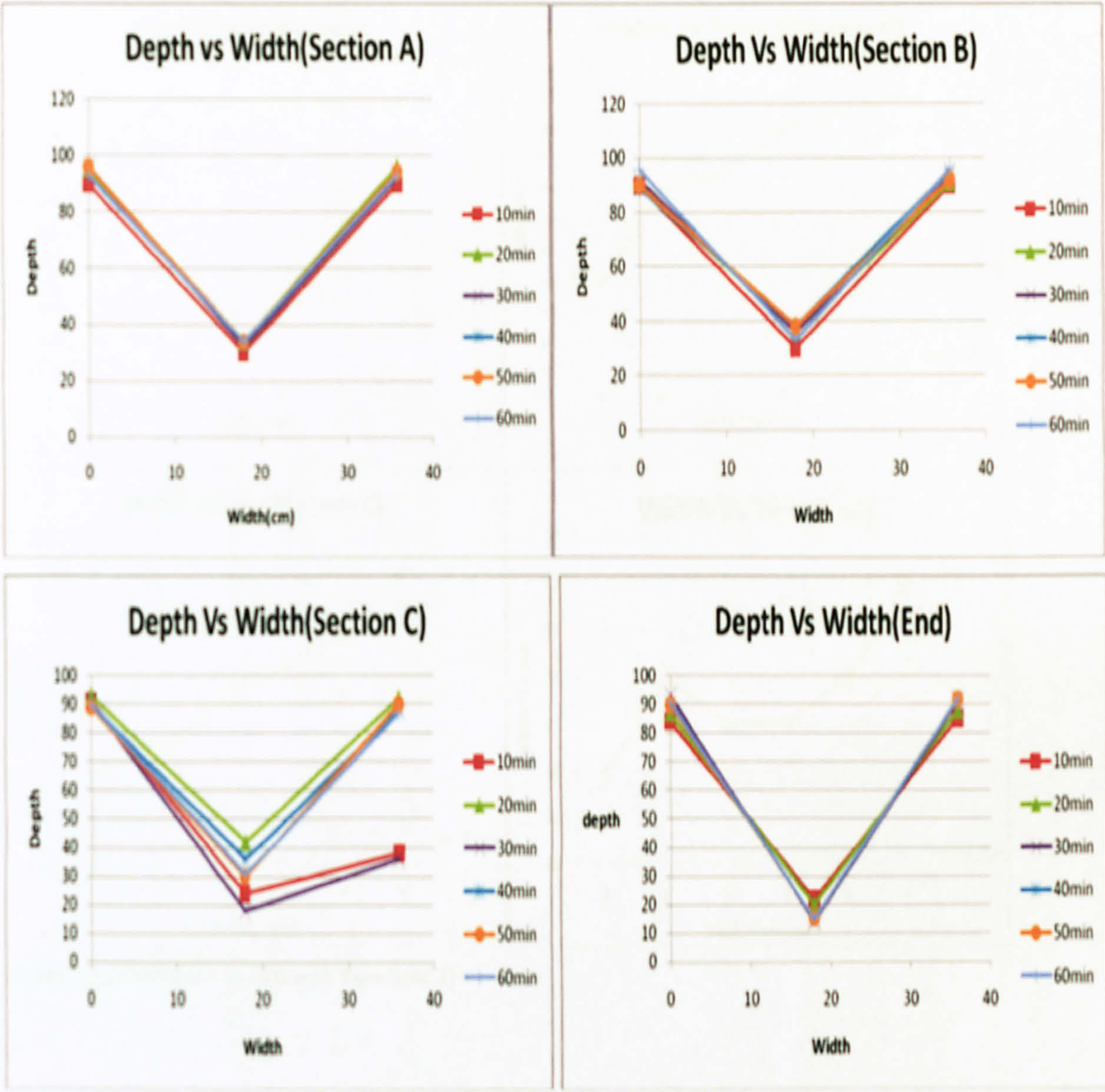


Figure 28: alteration of depth with time (test 3)

Track of Depth alteration with time

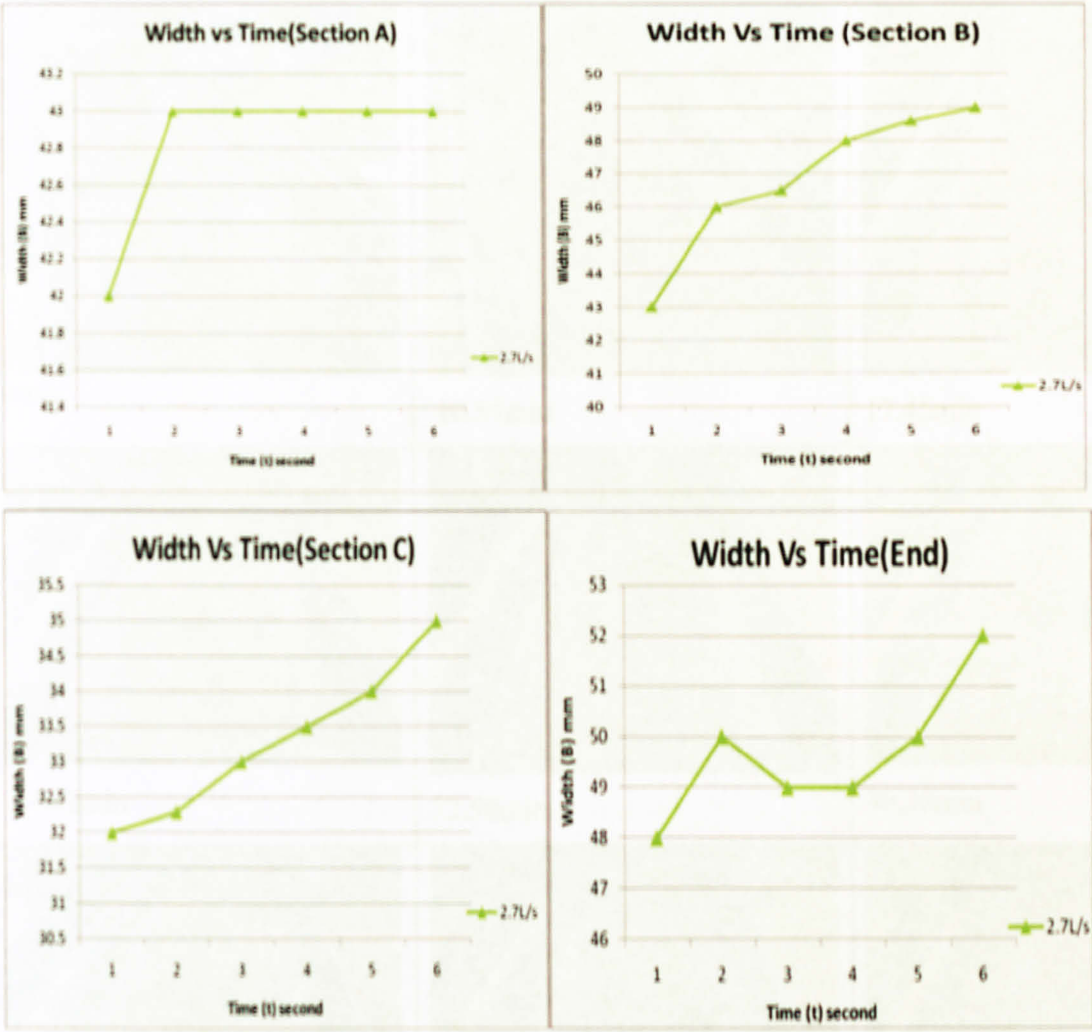
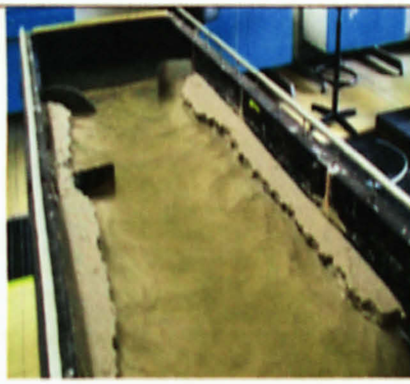


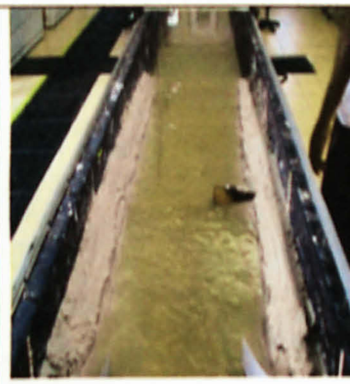
Figure 29: alteration of width with time (test 3)

4.5.4 Experiment4 (l 1.1lit/sec (40cm))

Table 10: Erosion of Bank with time for Experiment 1.1lit/sec for 40cm width channel

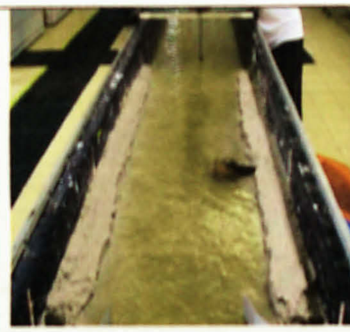

0min


10.55min

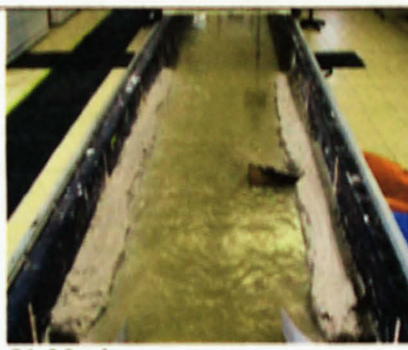

17.45min


24.42min


32.58min


40.38min


46.8min


51.33min

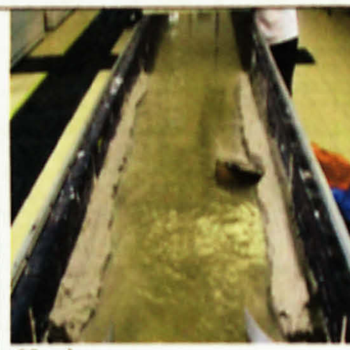

60min

Table 10.1.Conditions of Sand before running

length	depth
410	45mm
920	45mm
1300	36mm

length	Width
410	40cm
920	40cm
1300	40cm

Table 10.2height of the bank

length	Left(mm)	Right(mm)
410	122	123
920	123	123
1300	123	122

Table 10 .3.Width(cm) during running

time	upstream	Groin	middle	downstr
14:15	40.2	26	40	39.5
14:25	39	26	41	39
14:35	40	27	40	41
14:55	39	27.5	40	40
15:05	40	28	40.5	40
15:15	40	29	40	42

Table 10 .4.Depth(mm) during running

	80mm			580mm			830mm		
	L	M	R	L	M	R	L	M	R
14:15	90	54	82	88	35	87	82	47	89
14:25	87	51	84	85	40	86	76	48	88
14:35	87	52	90	86	41	88	84	58	85
14:55	88	48	85	86	48	87	86	44	87
15:05	86	45	87	85	47	85	83	36	85
15:15	90	46	90	86	43	89	85	36	84

1580mm			
R	L	M	R
89	90	28	88
88	87	29	87
85	87	30	85
87	83	29	78
85	83	27	88
84	87	38	89

Track of depth alteration with time

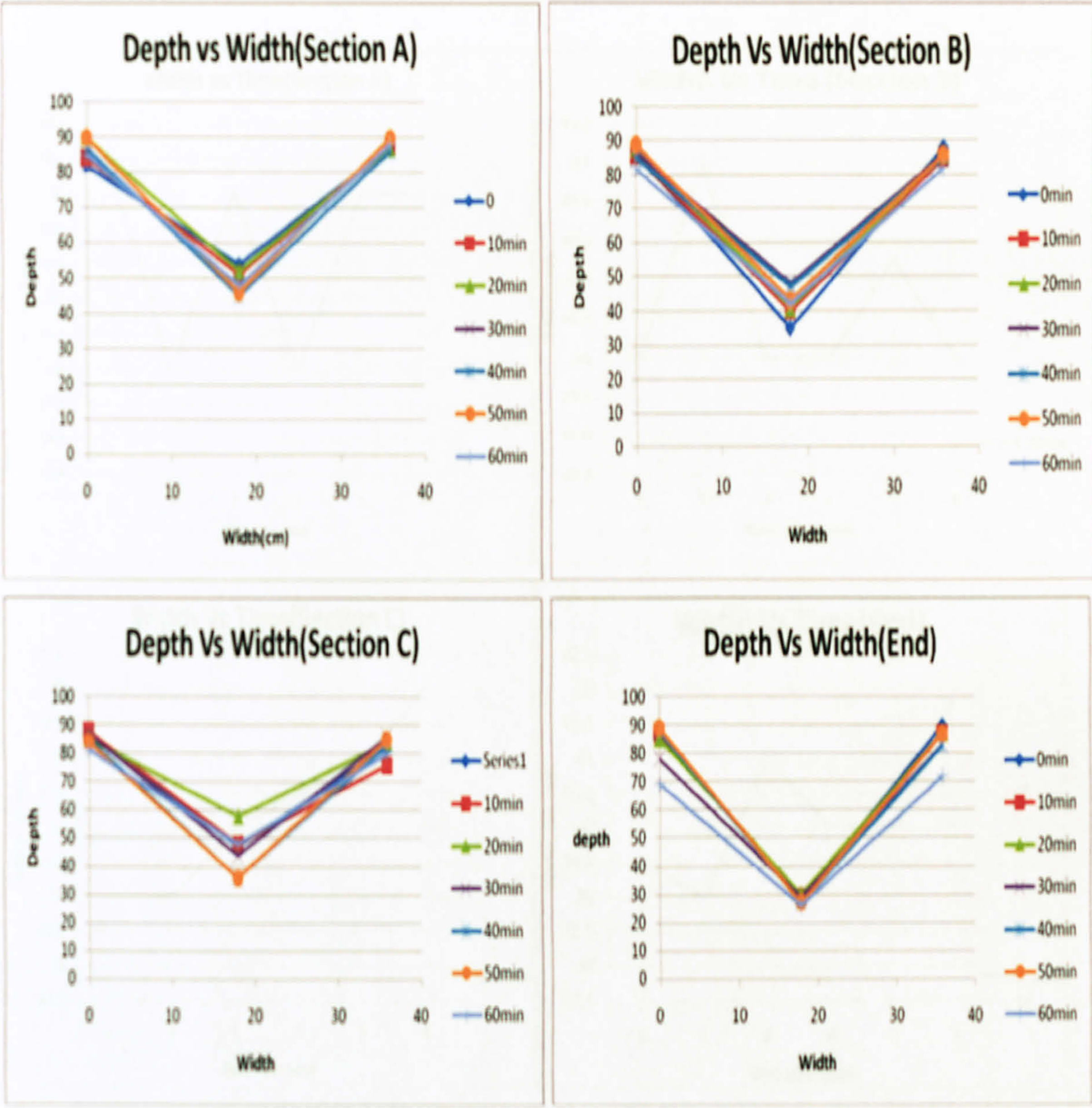


Figure 30: alteration of depth with time (test 4)

Track of width alteration with time

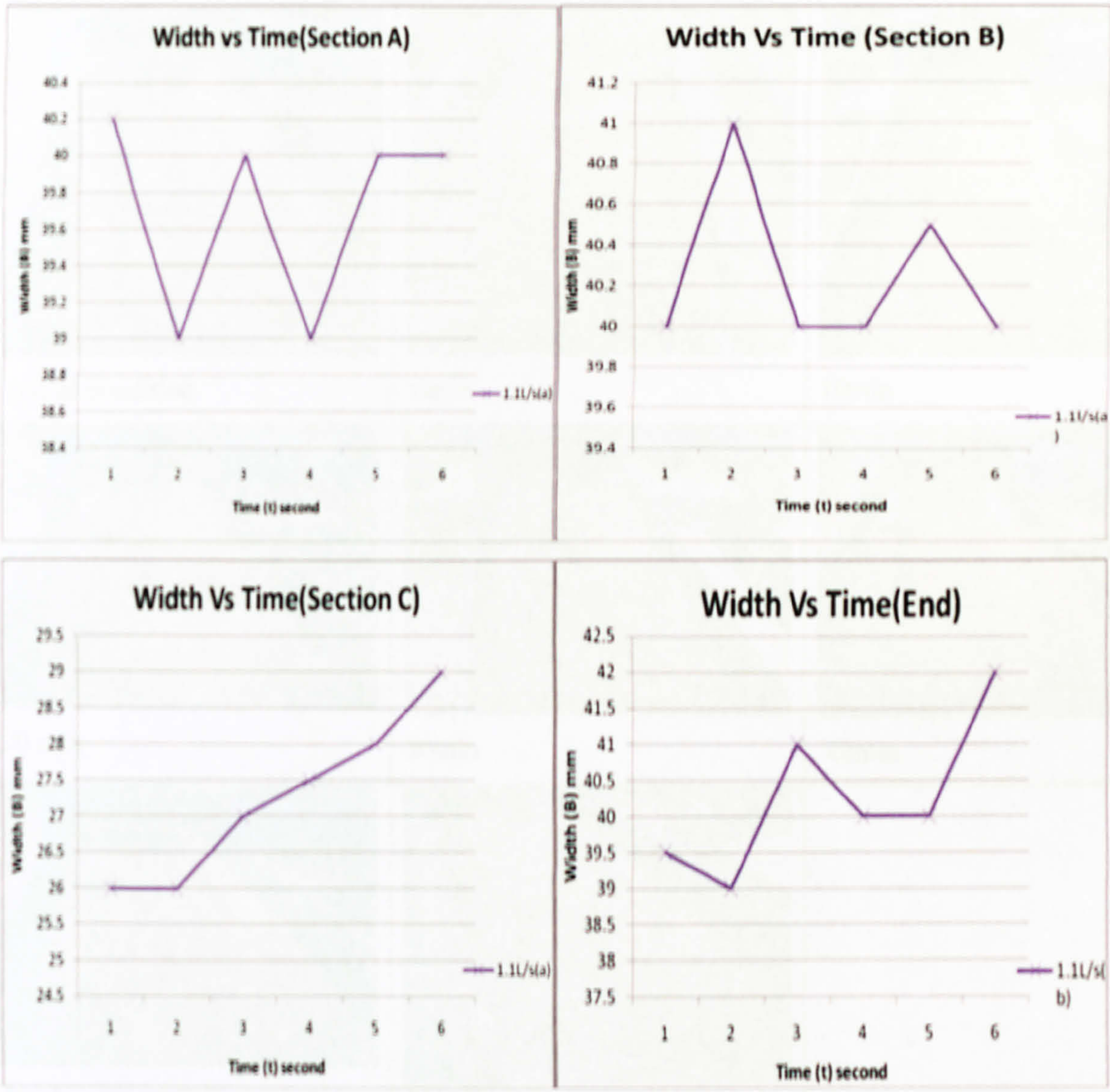


Figure 31: alteration of width with time (test 4)

4.5.5 Experiment 5 (Q=1.71 lit/sec (40cm)

Table 11.Erosion of Bank with time for Experiment 1.1lit/sec for 40cm width channel

Initial condition

0min

10min

20 min

30min

40min

50min

60 min

Table 11.1 Conditions of Sand before runing

Length	depth
320	50mm
750	46mm
1300	44mm

length	Width
320	40cm
750	40cm
1300	40cm

Table 11. 2 height of the bank

Length	Left(mm)	Right(mm)
320	130	130
750	126	130
1300	116	120

Table 11.3.width(cm) during running

Time	upstream	groin	middle	downstr
0min	40	29	39.5	40
10min	41	32.5	40	41
20min	41	33	43	44.5
30min	41	34	44	47
40min	42	37	48	49
50min	43	38	48	49
60min	44	39	48.5	49

Table 11.4Depth(mm) during running

	80mm			580mm			830mm			1580mm		
	L	M	R	L	M	R	L	M	R	L	M	R
0min	91	55	96	91	65	82	86	48	82	85	44	82
10min	99	55	96	99	58	86	97	43	87	95	40	94
20min	95	58	94	94	52	78	92	68	92	92	52	91
30min	99	58	99	95	70	72	98	62	92	95	52	91
40min	100	75	100	98	55	90	95	62	95	95	70	92
50min	97	40	98	98	54	86	94	60	95	95	70	82
60min	99	40	98	95	60	80	100	74	94	86	65	86

Track of depth alteration with time

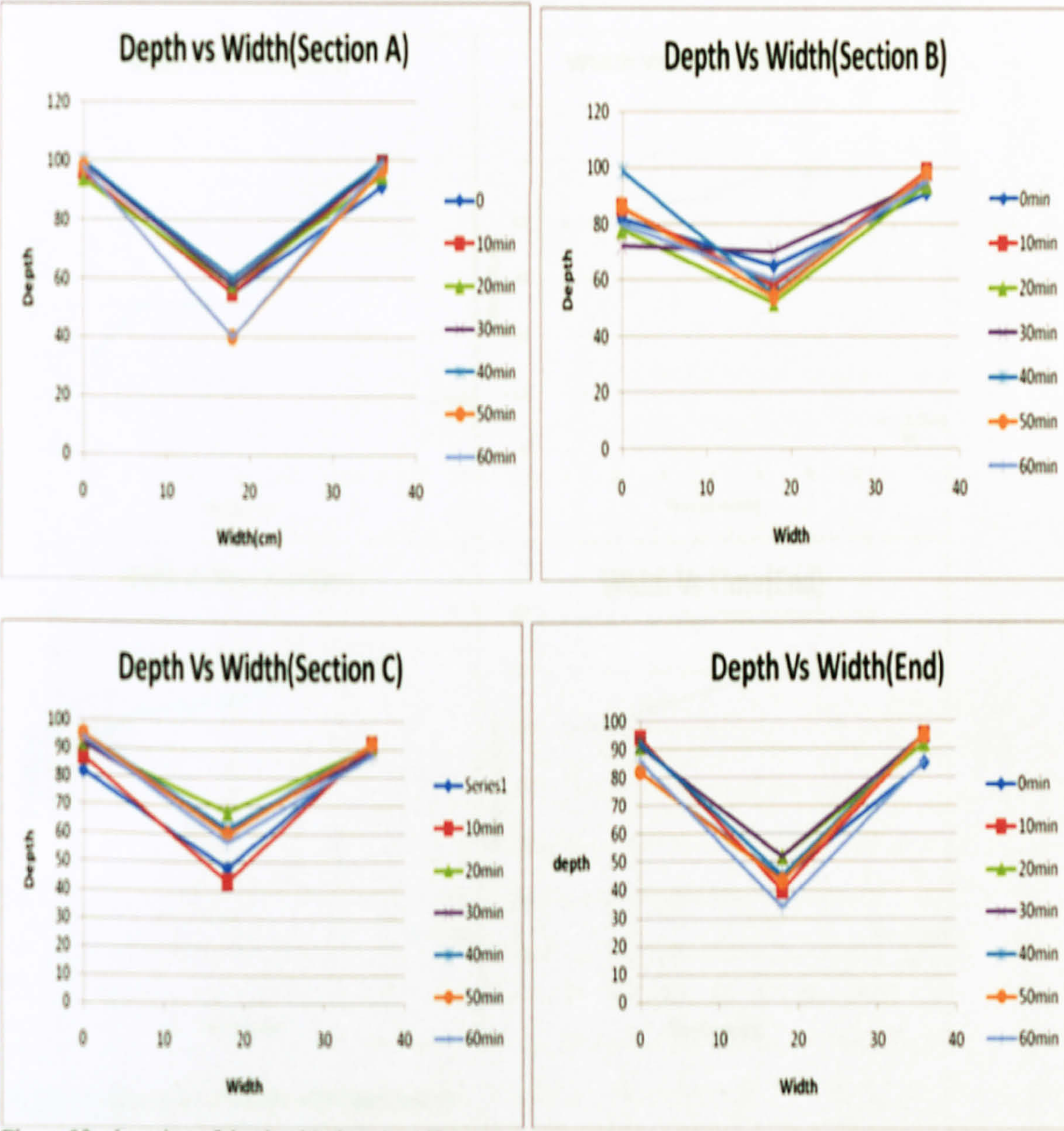


Figure 32: alteration of depth with time (test 5)

Track of width alteration with time

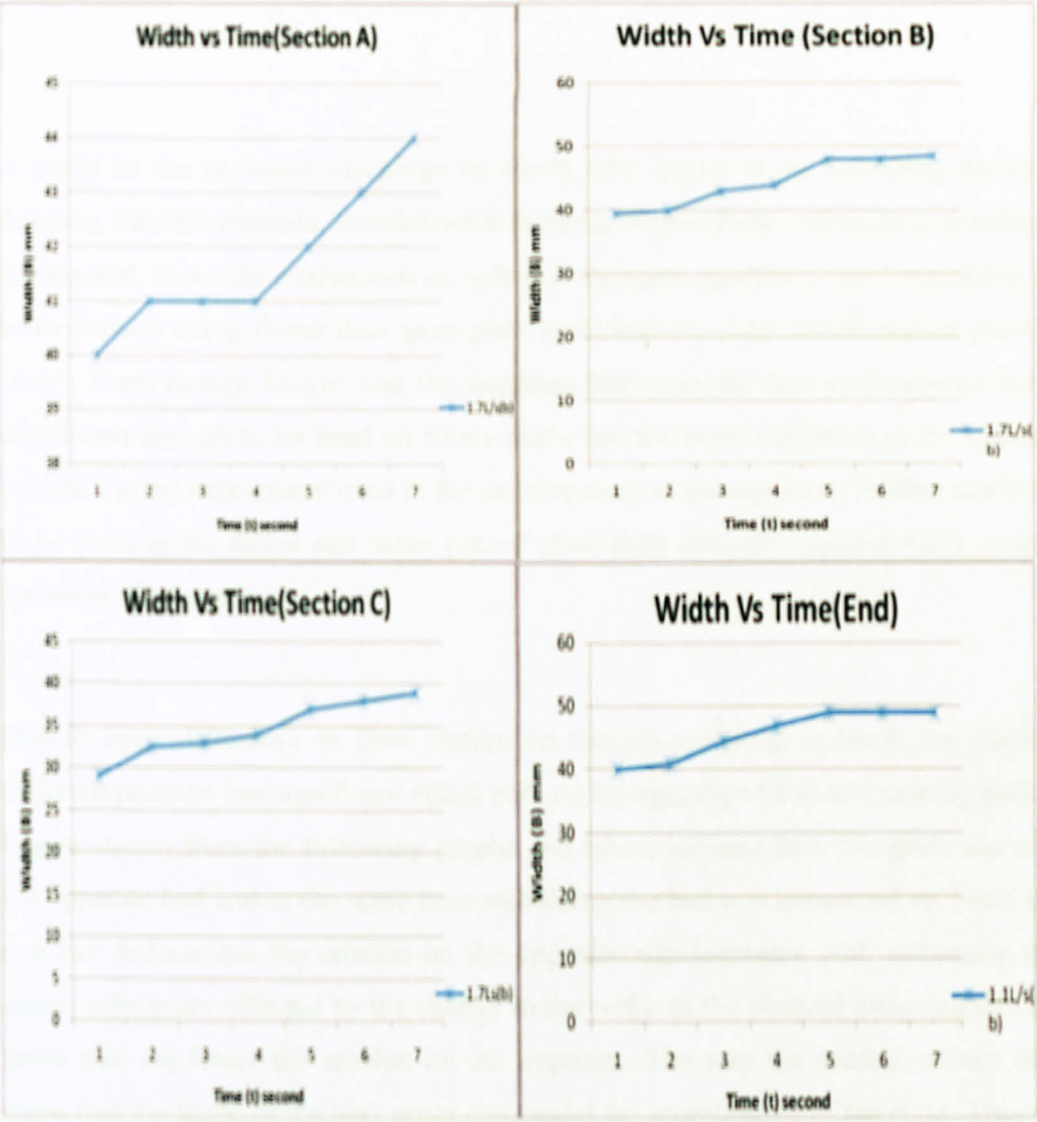


Figure 33: alteration of width with time (test 5)

CHAPTER 5

CONCLUSIONS

A study on the sediment discharge on rivers with aspect to the following equations DuBoys' formula, Shield's formula, Schoklitsch's formula, Meyer-Peter's formula and Ackers-White were invstigated. From the evaluations on selected transport equations, the 5 equations namely which were derived using flume data gave poor performance when tested against practical data (arc-view). Even though Meyer was the equation that gave the best performance but still it is not significant enough to be used on rivers that's has the same condition as the channel in the tank despite a good data source used in the development of the equation. Further analysis is necessary to be done in the future and more sets of good field data are required for a good prediction of sediment discharge.

Due to large difference in flow pattern on various positions in bend, the placing groin on different position has significant effect both on topography of bed and scoring peak around it. Figure shown from the following graphs and tables indicate how the groin aid with erosion on the opposite bed and at the same time stabilizing the bed it is connected to. From the data obtain one can deduce that the erosion on the opposite size increases with increasing discharge. The groins effects are affected by the change in the width of the channel deducing that the smaller the groin size the lesser the erosion on the opposite. The way the erosion occurs on the graphs I show that the angle of the way groin can model the morphology of the river. Transversal profiles show that there is a correlation between maximum eroding with and groin size and as the size increases, the rate of erosion increases. There is also a direct correlation, and as the discharge increases crease the scoring depth will increase. Further analysis of the groin angle affects the geometry of the channel.

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APPENDIX A

Sediment Discharge prediction using Ackers and White's (1973) Method

APPENDIX B

Sediment Discharge prediction using DuBoys' formula, Shield's formula, Schoklitsch's formula, Meyer-Peter's formular for experiment 7

APPENDIX C

Sediment Discharge prediction using Ackers and White's (1973) Method DuBoys' formula, Shield's formula, Schoklitsch's formula, Meyer-Peter's formula for experiment 1

APPENDIX E

Incipient Motion Analysis

APPENDIX F

Gann Chat

APPENDIX G

Friction due to channel irregularities as a function of sediment transport

APPENDIX H

Properties of water

APPENDIX I

Experiment 1(arc-view coordinates)

APPENDIX J

Experiment 7(arc-view coordinates)

APPENDIX K

Experiment 7(arc-view coordinates)

APPENDIX A

Sediment Discharge prediction using Ackers and White's (1973) Method

The total sediment transport can be determined from computing the parameters dgr, m, A, n, C, Fgr, Ggr and X. using the specific gravity of the sediment is 2.6, the parameters dgr can be determined as

-At a temperature of 28.3°C , the water kinematic viscosity (Yang, 1996)(see APPENDIX) is $\upsilon = 0.832 \times 10^{-6}\ m^2/s$

-Assuming a shape factor of 0.7 (Yang, 1996); the fall velocity is

$\omega = 0.12m/s$

-The shear velocity is

$U^* = (gyavgS)1/2 = (9.81 \times 0.08 \times 0.0015)^{1/2} = 0.0358m/s$

-The shear velocity Reynolds number is

$Re = (U^* D50)/\upsilon = (0.0343 \times 0.003)/ 0.832 \times 10^{-5} = 11.6$

$$d_{gr} \quad = D_{50}\left[\frac{g(\gamma_s/\gamma - 1)}{\upsilon^2}\right]$$

$$= 0.00025 \times ((9.81 \times 1.6)/ (0.81\times 10^{-6})_2))^{1/3} = 0.524$$

The parameters m, A, n, and C are

$m = (9.66/ dgr)+1.34 = (9.66/.252)+1.34 = 3.18$

$A = (0.23/ (dgr)^{1/2})+0.14 = (0.23/(0.527)1/2)+0.14 = 0.24$

$n = 1-0.56\log dgr = 1-0.56\log 0.527 = 0.597$

C = 10[2.86logdgr-(logdgr)^2-3.53] = 10[2.86logo.527-(log0.527)^2-3.53] = 0.032

For U* = 0.0358 and coefficient in rough turbulent equation (α) = 10, the mobility number Fgr can be computed as

$$F_{gr} = \frac{U_*^n}{\left[gD_{50}(\gamma_s/\gamma - 1)\right]^{1/2}}\left[\frac{3.7}{(32)^{1/2}\log(\alpha y_{avg}/D_{50})}\right]^{1-n}$$

$= [(0.0343)^{0.2}/(9.81 \times (0.00092)(1.74)^{1/2}] \times [3.7/(32)1/2\log(10*0.08/0.00092)]^{0.8}$

$= 1.2$

The dimensionless sediment transport rate Ggr is

$$G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right)^m$$

$= 0.0102 \times ((1.2/0.18)-1)^{1.7}$

$= 0.59$

And rate of sediment transport function in terms of mass flow per unit mass flow rate (X) is

$$X = \frac{G_{gr} D_{50}(\gamma_s/\gamma)}{y_{avg}(U_*/V_{avg})^n}$$

$= (0.58*0.00025*2.74)/(0.0025*(0.0358/0.14)\text{^}0.5) = 0.0816$

$=$ Cts

$= 816.218$ ppm by weight

$q=\gamma_w QX=9800*0.0041*0.0068$

$=0.27$kg.s

$=0.00027(m^3/s)/m$

APPENDIX- B

The Bed Sediment Load

Collected Data:

D (avarage depth) =	0.1	m			
S (slope) =	0.034				
d_{50} =	0.25	mm =	0.00025	m	
Q(water discharge)=	4.1	L/s =	0.0041	m^3/s	
q(dichg/unit width)=	0.006833	$(m^3/s)/m$			
b (channel width) =	0.6	m			
Temperature =	28.6°C	=	83.5°F		
ν(kinematic visety)=	$0.894x10^5$	ft2/s	=	$0.083x10^{-5}$	m^2/s
t (Time during exp) =	3600	second			
d_s (depth of sand) =	45	mm	=	0.045	m

DuBoys' Formula

$$q_b = \frac{0.173}{d_{50}^{0.75}} \quad \tau(\tau-\tau_c)$$

$\tau =$ γDS

$=$ 1000 0.1 0.034

$\tau =$ 3.4 kg/m^2

from figure 4.2(a) in Yang's book with d_{50}=0.25mm, τ_c= 0.09 kg/m^2

$$q_b = \frac{0.173}{0.001988177} \quad 3.4 \quad 3.31$$

$q_b =$ 979.26 $(m^3/s)/m$

Shield's Formula

$$\frac{q_b\ \gamma_s}{q\ S\gamma} = \frac{10(\tau-\tau_c)}{(\gamma s-\gamma)d_{50}}$$

The Shield's diagram (fig 2.2 page 22 in Yang's book) is used to calculate τ_c:

$U_* =$ $(gDS)^{1/2}$

$=$ $[$ 9.81 0.1 0.034 $]^{1/2}$

$U_* =$ 0.182630775 m/s

$$R_* = \frac{U^*d}{\nu} = \frac{0.18263 \quad 0.00025}{0.083x10\text{-}5}$$

$R_* =$ 55.0092696

$$\frac{\tau_c}{(\gamma s-\gamma)d_{50}} = 0.038$$

$$\frac{\tau_c}{1650 \quad 0.00025} = 0.038$$

$\tau_c =$ 0.015675 kg/m^2

therefore;

$$\frac{q_b \quad 2650}{0.00683 \quad 0.034 \quad 1000} = \frac{10 \quad 3.384325}{1650 \quad 0.00025}$$

$q_b =$ 0.0072 (kg/s)/m = 7.19306E-06 $(m^3/s)/m$

Schoklitsch's Formula

$$q_b = \frac{7000}{d_{50}^{0.5}} S^{3/2} (q - q_c)$$

$$q_c = 1.94 \times 10^{-5} \frac{d_{50}}{S^{4/3}}$$

$$q_c = 1.94 \times 10^{-5} \frac{0.00025}{0.011027}$$

$q_c =$ 4.39825E-07 $(m^3/s)/m$

therefore;

$$q_b = \frac{7000}{0.016} \quad 0.006269 \quad 0.00683$$

$q_b =$ 18.96 (kg/s)/m = 0.019 $(m^3/s)/m$

Meyer-Peter's Formula

$$\frac{0.4}{d_{50}} q_b^{2/3} = \left(\frac{q^{2/3} S}{d_{50}}\right) - 17$$

$$\frac{0.4}{0.00025} q_b^{2/3} = \left(\frac{0.036 \quad 0.034}{0.00025}\right) - 17$$

$q_b^{2/3}$ = -0.00756

q_b = 0.00066 (kg/s)/m = 6.57938E-07 $(m^3/s)/m$

1 kg pure water = 1 dm^3

1 m^3 of water weights = 1 ton = 1000kg

Arc View Calculation

Area = 739179.534 mm^2 = 0.74 m^2

Volume = 30936166.67 mm^3 = 0.03 m^3

Q after flowing water = 8.59E-06 m^3/s

Q before flowing water = 9.24E-06 m^3/s

Q_b total = 6.46365E-07 m^3/s

$q_b =$ 1.07727E-06 $(m^3/s)/m$

APPENDIX -C

The Bed Sediment Load

Collected Data:

D (avarage depth) =	0.085	m			
S (slope) =	0.034				
d_{50} =	0.25	mm =	0.00025	m	
Q(water discharge)=	1.16	L/s =	0.00116	m^3/s	
q(dichg/unit width)=	0.0019333	$(m^3/s)/m$			
b (channel width) =	0.6	m			
Temperature =	29.3°C	=	84.74	°F	
ν(kinematic viscty)=	0.881×10^{-5}	ft^2/s	=	2.69E-06	m^2/s
t (Time during exp) =	3600	second			
d_s (depth of sand) =	45	mm	=	0.045	m

DuBoys' Formula

$$q_b = \frac{0.173}{d_{50}^{0.75}} \tau(\tau-\tau_c)$$

$\tau = \gamma DS$

$= 1000 \quad 0.085 \quad 0.034$

$\tau = 2.89$ kg/m^2

from figure 4.2(a) in Yang's book with d_{50}=0.25mm, τ_c= 0.09 kg/m^2

$$q_b = \frac{0.173}{0.001988177} \quad 2.89 \quad 2.8$$

$q_b = 704.12$ $(m^3/s)/m$

Shield's Formula

$$\frac{q_b \gamma_s}{q S \gamma} = \frac{10(\tau-\tau_c)}{(\gamma s-\gamma)d_{50}}$$

The Shield's diagram (fig 2.2 page 22 in Yang's book) is used to calculate τ_c:

$U_* = (gDS)^{1/2}$

$= (9.81 \quad 0.085 \quad 0.034)^{1/2}$

$U_* = 0.168377255$ m/s

$$R_e = \frac{U^*d}{\nu} = \frac{0.16838 \quad 0.00025}{2.68705E-06}$$

$R_e = 15.67$

$$\frac{\tau_c}{(\gamma s-\gamma)d_{50}} = 0.031$$

$$\frac{\tau_c}{1650 \quad 0.00025} = 0.031$$

$\tau_c = 0.0127875$ kg/m^2

therefore;

$$\frac{q_b \quad 2650}{0.00193 \quad 0.034 \quad 1000} = \frac{10 \quad 2.877213}{1650 \quad 0.00025}$$

$q_b =$ 0.0017 (kg/s)/m = 1.73017E-06 $(m^3/s)/m$

Schoklitsch's Formula

$$q_b = \frac{7000}{d_{50}^{0.5}} \quad S^{3/2} \quad (q-q_c)$$

$$q_c = 1.94\times10^{-5} \quad \frac{d_{50}}{S^{4/3}}$$

$$q_c = 1.94\times10^{-5} \quad \frac{0.00025}{0.0110271}$$

$q_c =$ 4.39825E-07 $(m^3/s)/m$

therefore;

$$q_b = \frac{7000}{0.016} \quad 0.0062693 \quad 0.00193$$

$q_b =$ 5.36 (kg/s)/m = 0.005 $(m^3/s)/m$

Meyer-Peter's Formula

$$\frac{0.4}{d_{50}} \quad q_b^{2/3} = \left(\frac{q^{2/3}S}{d_{50}}\right) \quad -17$$

$$\frac{0.4}{0.00025} \quad q_b^{2/3} = \left(\frac{0.01552 \quad 0.034}{0.00025}\right) \quad -17$$

$q_b^{2/3}$ = -0.00931

q_b = 0.0009 (kg/s)/m = 8.97747E-07 $(m^3/s)/m$

1 kg pure water = 1 dm^3

1 m^3 of water weights = 1 ton = 1000kg

Arc View Calculation

Area = 416943.79 mm^2 = 0.42 m^2

Volume = 17537870 mm^3 = 0.02 m^3

Q after flowing water = 4.872E-06 m^3/s

Q before flowing water = 5.212E-06 m^3/s

Q_b total = 3.40167E-07 m^3/s

$q_b =$ 5.66945E-07 $(m^3/s)/m$

APPENDIX- D

The Bed Sediment Load

Collected Data:

D (avarage depth) =		0.087	m		
S (slope)	=	0.034			
d_{50}	=	0.25	mm =	0.00025	m
Q(water discharge)=		2.15	L/s =	0.00215	m^3/s
q(dichg/unit width)=		0.0035833	$(m^3/s)/m$		
b (channel width) =		0.6	m		
Temperature =		29.6°C	=	85.28	°F
ν(kinematic viscty)=		0.875×10^{-5}	ft^2/s	=	2.66875E-06
t (Time during exp) =		3600	second		
d_s (depth of sand) =		45	mm	=	0.045

DuBoys' Formula

$$q_b = \frac{0.173}{d_{50}^{0.75}}\ \tau(\tau-\tau_c)$$

$\tau = \gamma DS$

$= 1000 \quad 0.087 \quad 0.034$

$\tau = 2.958$ kg/m^2

from figure 4.2(a) in Yang's book with d_{50}=0.25mm, τ_c= 0.09

$$q_b = \frac{0.173}{0.001988177}\ 2.958 \quad 2.868$$

$q_b = 738.19$ $(m^3/s)/m$

Shield's Formula

$$\frac{q_b\,\gamma_s}{q\,S\gamma} = \frac{10(\tau-\tau_c)}{(\gamma s-\gamma)d_{50}}$$

The Shield's diagram (fig 2.2 page 22 in Yang's book) is used to calculate τ_c:

$U_* = (gDS)^{1/2}$

$= (9.81 \quad 0.087 \quad 0.034)^{1/2}$

$U_* = 0.170346647$ m/s

$$R_* = \frac{U^*d}{\nu} = \frac{0.170346647 \quad 0.00025}{2.66875E-06}$$

$R_* = 15.96$

$$\frac{\tau_c}{(\gamma s-\gamma)d_{50}} = 0.031$$

$$\frac{\tau_c}{1650 \quad 0.00025} = 0.031$$

$\tau_c = 0.0127875$ kg/m^2

therefore:

q_b	2650		=	10	2.9452125
0.003583333	0.034	1000		1650	0.00025
q_b =	0.0033	(kg/s)/m	=	3.28256E-06	$(m^3/s)/m$

Schoklitsch's Formula

$$q_b = \frac{7000}{d_{50}^{0.5}} S^{3/2} (q-q_c)$$

$$q_c = 1.94\times10^{-5} \frac{d_{50}}{S^{4/3}}$$

$$q_c = 1.94\times10^{-5} \frac{0.00025}{0.0110271}$$

q_c = 4.39825E-07 $(m^3/s)/m$

therefore:

$$q_b = \frac{7000}{0.016} \quad 0.0062693 \quad 0.003582894$$

q_b = 9.94 (kg/s)/m = 0.010 $(m^3/s)/m$

Meyer-Peter's Formula

$$\frac{0.4}{d_{50}} q_b^{2/3} = \left(\frac{q^{2/3} S}{d_{50}}\right) -17$$

$$\frac{0.4}{0.00025} q_b^{2/3} = \left(\frac{0.023412257 \quad 0.034}{0.00025}\right) -17$$

$q_b^{2/3}$ = -0.008634958

q_b = 0.000802399 (kg/s)/m =

1 kg pure water	=	1 dm^3		
1 m^3 of water weights	=	1 ton	=	1000kg

Arc View Calculation

Area =	507489.978	mm^2	=	0.51	m^2
Volume =	4163278.333	mm^3	=	0.004	m^3

Q after flowing water = 1.156E-06 m^3/s

Q before flowing water = 6.344E-06 m^3/s

Q_b total = 5.18716E-06 m^3/s

q_b = 8.64526E-06 $(m^3/s)/m$

Exp ($(m^3/s)/m$)	Arc View	DuBoys'	Shield's	Schoklitsch's	Meyer-Peter's

13022009	8.64526E-06	738.19	3.28256E-06	0.010	8.02399E-07
05032009	5.66945E-07	704.12	1.73017E-06	0.00536481	8.97747E-07
25032009	1.07727E-06	979.26	7.19306E-06	0.018964922	6.57938E-07

Exp ((mm^3/s)/mm	Arc View	DuBoys'	Shield's	Schoklitsch's	Meyer-Peter's
13022009	8645.3	7.382E+11	3282.6	9944439.5	802.4
05032009	566.9	7.041E+11	1730.2	5364809.9	897.7
25032009	1077.3	9.793E+11	7193.1	18964922.1	657.9

62.03051866	90.71863
205.1736756	-58.34832561
-567.7093884	38.92569009

%Error

Exp ((m^3/s)/m)	Arc View	DuBoys'	Shield's	Schoklitsch's	Meyer-Peter's
13022009	8645.3	8.539E+09	62.03051866	114927.5954	90.71863
05032009	566.9	1.242E+11	205.1736756	946166.8797	58.34832561
25032009	1077.3	9.09E+10	567.7093884	1760354.429	38.92569009

APPENDIX E

Incipient Motion

Reynolds Number

$$Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu} = \frac{QD}{\nu A}$$

Where
ρ = density of the fluid (kg/m3)
V = mean fluid velocity (m/s)
D = diameter (m)
μ = dinamic viscosity of the fluid (Pa.s or N.s/m2)
ν = kinematic viscosity ($\nu = \mu/\rho$) (m2/s)
Q = volumetric flow rate (m3/s)
A = cross-sectional area (m2)

Quartz-rich sediment (ρs) = 2650 kg/m3
Water (ρ) = 1000 kg/m3
Specific weight of water = $\gamma = \rho g$ = 1000 kg/m3x9.81 m/s2 = 9810 N/m3

Temperature was 28.6°C from experiment at 23 march 2009 with 0.25 sediment size
Calculation for fall velocity:
From Table 1.1 page 3 in Yang's book with temperature 28.6°C (83.5°F)

d = 0.25 mm = 0.00025 m
ρs = 2650 kg/m3
ν = 0.894x10^5 ft2/s = 0.083x10^-5 m2/s
Ws = 1/6 $\pi d^3(\rho s-\rho)g$
= 1/6π(0.00025^3)(2650-1000)(9.81)
= 0.000000132 kg.m/s2 = 0.000000132 N

$$\frac{Ws}{\rho s\ \nu 2} = \frac{0.000000132}{1000*(0.083\text{x}10^{-5})^2} = 72.31$$

From Figure 1.2,page 9 in Yang's book, Cd = 1.5
At terminal fall velocity, Fd = Ws

$$\omega = \left(\frac{2\ Fd}{Cd\ A\ \rho s}\right)^{0.5} \qquad A = bxy = 0.6\text{x}0.065 = 0.039\ \text{m2}$$

$$= \left(\frac{2\text{x}0.000000132}{1.5\text{x}0.039\text{x}2650}\right)^{0.5}$$

= 4.12668E-05 m/s

check = $Re = \omega d/\nu = \frac{4.12668\text{E-05} \quad 0.00025}{0.083\text{x}10^{-5}}$ = 0.01243 (not same

U.S. Bureau of Reclamation Method
Critical tractive force $\tau c = \gamma DS$
Mean channel depth (D) = 0.065 m
Stream gradient (S) = 0.034
τc = 1x0.065x0.034 = 0.00221 N/m2

Dimensionless shear stress

$\tau^* = \dfrac{\tau c}{(\gamma s-\gamma)d} = \dfrac{0.00221}{(2.65-1)*0.00025} =$ 5.36 N/m2

Yang's Method

Dimensionless critical velocity

From Figure 2.6 page 30 in Yang's book

$U^* = (\tau/\rho)^{\wedge}0.5$

$= \left(\dfrac{0.00221}{2.65}\right)^{\wedge}0.5$

$= 0.02888$

$Re = U^*d/v$

$= \dfrac{0.02888 \quad 0.00025}{0.083x10^{\wedge}-5} =$ 8.698

$\dfrac{Vcr}{\omega} =$ 3.5 (From Figure 2.6 page 30 in Yang's book)

$\dfrac{Vcr}{4.12668E-05} =$ 3.5

Vcr = 0.000144434 m/s

APPENDIX F

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Research work	■	■	■					Mid-semester break							
2	Submission of Progress Report 1				●											
3	Design and simulation					■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar									●						
6	Simulation									■	■	■	■			
7	Poster Exhibition											●				
8	Submission of Dissertation (soft bound)													●		
9	Oral Presentation														●	
10	Submission of Project Dissertation (Hard Bound)															●

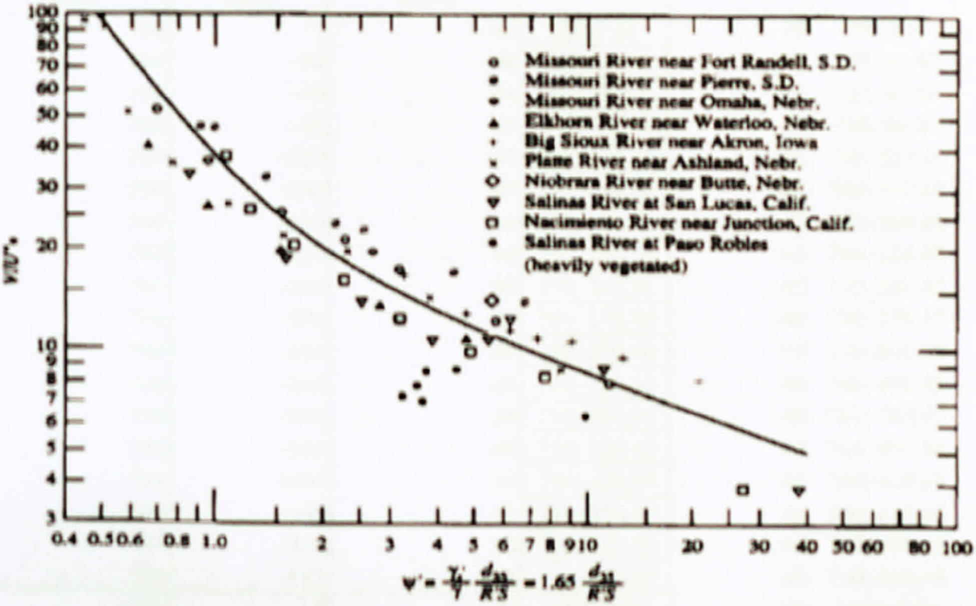
● Suggested milestone

■ Process

APPENDIX - F

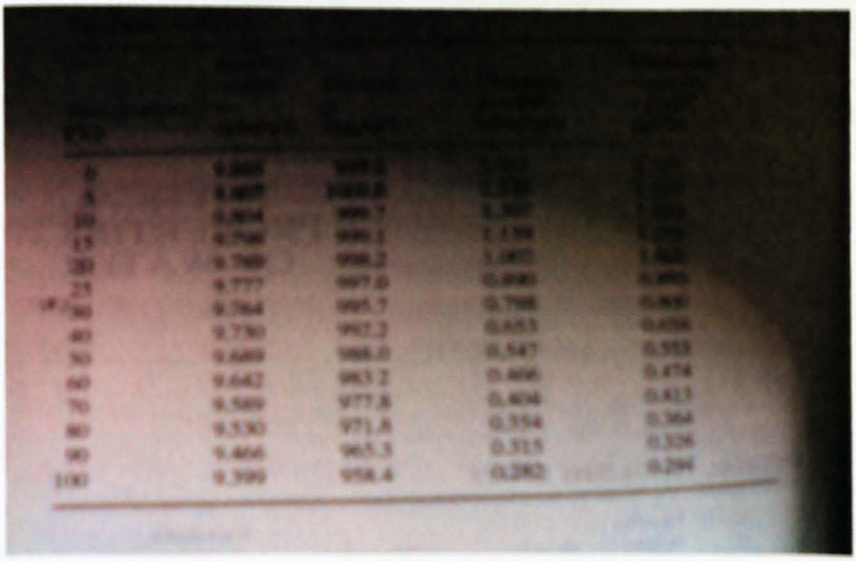
APPENDIX G

Fric~ionlo ss due to channel irregularities as a function of sediment transport rate (Einstein and Barbarossa, 1952)



APPENDIX H

Properties of water



0	9.805	999.8	[illegible]	[illegible]
5	9.807	1000.0	[illegible]	[illegible]
10	9.804	999.7	1.307	[illegible]
15	9.798	999.1	1.139	[illegible]
20	9.789	998.2	1.002	1.003
25	9.777	997.0	0.890	0.893
30	9.764	995.7	0.798	0.800
40	9.730	992.2	0.653	0.658
50	9.689	988.0	0.547	0.553
60	9.642	983.2	0.466	0.474
70	9.589	977.8	0.404	0.413
80	9.530	971.8	0.354	0.364
90	9.466	965.3	0.315	0.326
100	9.399	958.4	0.282	0.294

APPENDIX I(Q=2.1 lit/sec)

Length (mm)	Width (mm)	Depth (mm)	Coordinate		
axis x	axis y	axis z			
790	0	46	790,0,46	45	790,0,45
790	-30	46	790,-30,46	45	790,-30,45
790	-60	44	790,-60,44	45	790,-60,45
790	-90	43	790,-90,43	45	790,-90,45
790	-120	40	790,-120,40	45	790,-120,45
790	-150	40	790,-150,40	45	790,-150,45
790	-180	40	790,-180,40	45	790,-180,45
790	-210	38	790,-210,38	45	790,-210,45
790	-240	39	790,-240,39	45	790,-240,45
790	-270	39	790,-270,39	45	790,-270,45
790	-300	40	790,-300,40	45	790,-300,45
790	-330	40	790,-330,40	45	790,-330,45
790	-360	39	790,-360,39	45	790,-360,45
790	-390	40	790,-390,40	45	790,-390,45
790	-420	38	790,-420,38	45	790,-420,45
790	-450	37	790,-450,37	45	790,-450,45
790	-480	40	790,-480,40	45	790,-480,45
790	-510	38	790,-510,38	45	790,-510,45
1200	0	44	1200,0,44	45	1200,0,45
1200	-30	44	1200,-30,44	45	1200,-30,45
1200	-60	44	1200,-60,44	45	1200,-60,45
1200	-90	43	1200,-90,43	45	1200,-90,45
1200	-120	40	1200,-120,40	45	1200,-120,45
1200	-150	40	1200,-150,40	45	1200,-150,45
1200	-180	40	1200,-180,40	45	1200,-180,45
1200	-210	39	1200,-210,39	45	1200,-210,45
1200	-240	39	1200,-240,39	45	1200,-240,45
1200	-270	39	1200,-270,39	45	1200,-270,45
1200	-300	40	1200,-300,40	45	1200,-300,45
1200	-330	40	1200,-330,40	45	1200,-330,45
1200	-360	39	1200,-360,39	45	1200,-360,45
1200	-390	40	1200,-390,40	45	1200,-390,45
1200	-420	38	1200,-420,38	45	1200,-420,45
1200	-450	37	1200,-450,37	45	1200,-450,45
1200	-480	40	1200,-480,40	45	1200,-480,45
1200	-510	41	1200,-510,41	45	1200,-510,45

APPENDIX J(Q=2.1 lit/sec)

Q=2.1 lit/sec

Length (mm)	Width (mm)	Depth (mm)	Coordinate	
axis x	axis y	axis z		
790	0	44	790,0,44	45 790,0,45
790	-30	44	790,-30,44	45 790,-30,45
790	-60	44	790,-60,44	45 790,-60,45
790	-90	43	790,-90,43	45 790,-90,45
790	-120	40	790,-120,40	45 790,-120,45
790	-150	40	790,-150,40	45 790,-150,45
790	-180	40	790,-180,40	45 790,-180,45
790	-210	39	790,-210,39	45 790,-210,45
790	-240	39	790,-240,39	45 790,-240,45
790	-270	39	790,-270,39	45 790,-270,45
790	-300	40	790,-300,40	45 790,-300,45
790	-330	40	790,-330,40	45 790,-330,45
790	-360	39	790,-360,39	45 790,-360,45
790	-390	40	790,-390,40	45 790,-390,45
790	-420	38	790,-420,38	45 790,-420,45
790	-450	37	790,-450,37	45 790,-450,45
790	-480	40	790,-480,40	45 790,-480,45
790	-510	41	790,-510,41	45 790,-510,45
1200	0	43	1200,0,43	45 1200,0,45
1200	-30	42	1200,-30,42	45 1200,-30,45
1200	-60	44	1200,-60,44	45 1200,-60,45
1200	-90	43	1200,-90,43	45 1200,-90,45
1200	-120	45	1200,-120,45	45 .200,-120,45
1200	-150	42	1200,-150,42	45 .200,-150,45
1200	-180	41	1200,-180,41	45 .200,-180,45
1200	-210	38	1200,-210,38	45 .200,-210,45
1200	-240	39	1200,-240,39	45 .200,-240,45
1200	-270	35	1200,-270,35	45 .200,-270,45
1200	-300	41	1200,-300,41	45 .200,-300,45
1200	-330	43	1200,-330,43	45 .200,-330,45
1200	-360	40	1200,-360,40	45 .200,-360,45
1200	-390	39	1200,-390,39	45 .200,-390,45
1200	-420	41	1200,-420,41	45 .200,-420,45
1200	-450	37	1200,-450,37	45 .200,-450,45
1200	-480	40	1200,-480,40	45 .200,-480,45
1200	-510	38	1200,-510,38	45 .200,-510,45

APPENDIX K(Q=4.1 lit/sec)

Length (mm)	Width (mm)	Depth (mm)	Coordinate		
axis x	axis y	axis z			
100	0	0	100,0,0	45	100,0,45
100	-30	12	100,-30,12	45	100,-30,45
100	-60	8	100,-60,8	45	100,-60,45
100	-90	8	100,-90,8	45	100,-90,45
100	-120	22	100,-120,22	45	100,-120,45
100	-150	42	100,-150,42	45	100,-150,45
100	-170	51	100,-170,51	45	100,-170,45
100	-180	43	100,-180,43	45	100,-180,45
100	-210	40	100,-210,40	45	100,-210,45
100	-240	43	100,-240,43	45	100,-240,45
100	-270	44	100,-270,44	45	100,-270,45
100	-300	48	100,-300,48	45	100,-300,45
100	-330	48	100,-330,48	45	100,-330,45
100	-350	54	100,-350,54	45	100,-350,45
100	-360	50	100,-360,50	45	100,-360,45
100	-390	35	100,-390,35	45	100,-390,45
100	-420	4	100,-420,4	45	100,-420,45
130	-80	11	130,-80,11	45	130,-80,45
130	-90	10	130,-90,10	45	130,-90,45
130	-120	13	130,-120,13	45	130,-120,45
130	-150	35	130,-150,35	45	130,-150,45
130	-180	54	130,-180,54	45	130,-180,45
130	-210	42	130,-210,42	45	130,-210,45
130	-240	41	130,-240,41	45	130,-240,45
130	-270	43	130,-270,43	45	130,-270,45
130	-300	44	130,-300,44	45	130,-300,45
130	-330	45	130,-330,45	45	130,-330,45
130	-360	52	130,-360,52	45	130,-360,45
130	-390	32	130,-390,32	45	130,-390,45
130	-420	12	130,-420,12	45	130,-420,45
130	-450	4	130,-450,4	45	130,-450,45
160	-120	18	160,-120,18	45	160,-120,45
160	-150	32	160,-150,32	45	160,-150,45
160	-180	54	160,-180,54	45	160,-180,45
160	-210	49	160,-210,49	45	160,-210,45
160	-240	42	160,-240,42	45	160,-240,45
160	-270	40	160,-270,40	45	160,-270,45
160	-300	41	160,-300,41	45	160,-300,45
160	-330	48	160,-330,48	45	160,-330,45
160	-360	60	160,-360,60	45	160,-360,45
160	-390	39	160,-390,39	45	160,-390,45
160	-420	18	160,-420,18	45	160,-420,45
160	-450	10	160,-450,10	45	160,-450,45

190	-120	22	190,-120,22	45	190,-120,45
190	-150	35	190,-150,35	45	190,-150,45
190	-180	54	190,-180,54	45	190,-180,45
190	-210	56	190,-210,56	45	190,-210,45
190	-240	41	190,-240,41	45	190,-240,45
190	-270	42	190,-270,42	45	190,-270,45
190	-300	44	190,-300,44	45	190,-300,45
190	-330	48	190,-330,48	45	190,-330,45
190	-360	50	190,-360,50	45	190,-360,45
190	-390	45	190,-390,45	45	190,-390,45
190	-420	34	190,-420,34	45	190,-420,45
190	-450	22	190,-450,22	45	190,-450,45
210	-130	27	210,-130,27	45	210,-130,45
210	-150	32	210,-150,32	45	210,-150,45
210	-180	29	210,-180,29	45	210,-180,45
210	-210	55	210,-210,55	45	210,-210,45
210	-240	36	210,-240,36	45	210,-240,45
210	-270	39	210,-270,39	45	210,-270,45
210	-300	36	210,-300,36	45	210,-300,45
210	-330	38	210,-330,38	45	210,-330,45
210	-360	52	210,-360,52	45	210,-360,45
210	-390	55	210,-390,55	45	210,-390,45
210	-420	38	210,-420,38	45	210,-420,45
210	-450	40	210,-450,40	45	210,-450,45
240	-150	30	240,-150,30	45	240,-150,45
240	-180	46	240,-180,46	45	240,-180,45
240	-210	53	240,-210,53	45	240,-210,45
240	-240	42	240,-240,42	45	240,-240,45
240	-270	44	240,-270,44	45	240,-270,45
240	-300	44	240,-300,44	45	240,-300,45
240	-330	43	240,-330,43	45	240,-330,45
240	-360	52	240,-360,52	45	240,-360,45
240	-390	63	240,-390,63	45	240,-390,45
240	-420	60	240,-420,60	45	240,-420,45
240	-450	50	240,-450,50	45	240,-450,45
270	-160	32	270,-160,32	45	270,-160,45
270	-180	40	270,-180,40	45	270,-180,45
270	-210	52	270,-210,52	45	270,-210,45
270	-240	49	270,-240,49	45	270,-240,45
270	-270	48	270,-270,48	45	270,-270,45
270	-300	35	270,-300,35	45	270,-300,45
270	-330	30	270,-330,30	45	270,-330,45
270	-360	43	270,-360,43	45	270,-360,45
270	-390	58	270,-390,58	45	270,-390,45
270	-420	70	270,-420,70	45	270,-420,45
270	-450	62	270,-450,62	45	270,-450,45
270	-480	69	270,-480,69	45	270,-480,45

300	-170	36	300,-170,36	45	300,-170,45
300	-180	37	300,-180,37	45	300,-180,45
300	-210	50	300,-210,50	45	300,-210,45
300	-240	56	300,-240,56	45	300,-240,45
300	-270	41	300,-270,41	45	300,-270,45
300	-300	20	300,-300,20	45	300,-300,45
300	-330	22	300,-330,22	45	300,-330,45
300	-360	41	300,-360,41	45	300,-360,45
300	-390	60	300,-390,60	45	300,-390,45
300	-420	61	300,-420,61	45	300,-420,45
300	-450	72	300,-450,72	45	300,-450,45
300	-480	70	300,-480,70	45	300,-480,45
300	-500	60	300,-500,60	45	300,-500,45
330	-180	43	330,-180,43	45	330,-180,45
330	-210	54	330,-210,54	45	330,-210,45
330	-240	48	330,-240,48	45	330,-240,45
330	-270	48	330,-270,48	45	330,-270,45
330	-300	32	330,-300,32	45	330,-300,45
330	-330	45	330,-330,45	45	330,-330,45
330	-360	57	330,-360,57	45	330,-360,45
330	-390	66	330,-390,66	45	330,-390,45
330	-420	65	330,-420,65	45	330,-420,45
330	-450	58	330,-450,58	45	330,-450,45
330	-480	54	330,-480,54	45	330,-480,45
330	-510	50	330,-510,50	45	330,-510,45
360	-180	38	360,-180,38	45	360,-180,45
360	-210	47	360,-210,47	45	360,-210,45
360	-240	47	360,-240,47	45	360,-240,45
360	-270	38	360,-270,38	45	360,-270,45
360	-300	45	360,-300,45	45	360,-300,45
360	-330	58	360,-330,58	45	360,-330,45
360	-360	64	360,-360,64	45	360,-360,45
360	-390	60	360,-390,60	45	360,-390,45
360	-420	48	360,-420,48	45	360,-420,45
360	-450	53	360,-450,53	45	360,-450,45
360	-480	50	360,-480,50	45	360,-480,45
360	-510	42	360,-510,42	45	360,-510,45
390	-170	57	390,-170,57	45	390,-170,45
390	-180	57	390,-180,57	45	390,-180,45
390	-210	46	390,-210,46	45	390,-210,45
390	-240	47	390,-240,47	45	390,-240,45
390	-270	38	390,-270,38	45	390,-270,45
390	-300	38	390,-300,38	45	390,-300,45
390	-330	44	390,-330,44	45	390,-330,45
390	-360	52	390,-360,52	45	390,-360,45
390	-390	46	390,-390,46	45	390,-390,45
390	-420	45	390,-420,45	45	390,-420,45

390	-450	50	390,-450,50	45	390,-450,45
390	-480	45	390,-480,45	45	390,-480,45
390	-510	43	390,-510,43	45	390,-510,45
420	-160	65	420,-160,65	45	420,-160,45
420	-180	55	420,-180,55	45	420,-180,45
420	-210	52	420,-210,52	45	420,-210,45
420	-240	55	420,-240,55	45	420,-240,45
420	-270	29	420,-270,29	45	420,-270,45
420	-300	30	420,-300,30	45	420,-300,45
420	-330	40	420,-330,40	45	420,-330,45
420	-360	38	420,-360,38	45	420,-360,45
420	-390	37	420,-390,37	45	420,-390,45
420	-420	38	420,-420,38	45	420,-420,45
420	-450	45	420,-450,45	45	420,-450,45
420	-480	44	420,-480,44	45	420,-480,45
420	-510	46	420,-510,46	45	420,-510,45
450	-145	59	450,-145,59	45	450,-145,45
450	-150	60	450,-150,60	45	450,-150,45
450	-180	59	450,-180,59	45	450,-180,45
450	-210	43	450,-210,43	45	450,-210,45
450	-240	38	450,-240,38	45	450,-240,45
450	-270	28	450,-270,28	45	450,-270,45
450	-300	30	450,-300,30	45	450,-300,45
450	-330	36	450,-330,36	45	450,-330,45
450	-360	39	450,-360,39	45	450,-360,45
450	-390	42	450,-390,42	45	450,-390,45
450	-420	35	450,-420,35	45	450,-420,45
450	-450	36	450,-450,36	45	450,-450,45
450	-480	34	450,-480,34	45	450,-480,45
450	-510	34	450,-510,34	45	450,-510,45
480	-120	51	480,-120,51	45	480,-120,45
480	-150	53	480,-150,53	45	480,-150,45
480	-180	53	480,-180,53	45	480,-180,45
480	-210	53	480,-210,53	45	480,-210,45
480	-240	44	480,-240,44	45	480,-240,45
480	-270	40	480,-270,40	45	480,-270,45
480	-300	40	480,-300,40	45	480,-300,45
480	-330	40	480,-330,40	45	480,-330,45
480	-360	35	480,-360,35	45	480,-360,45
480	-390	42	480,-390,42	45	480,-390,45
480	-420	50	480,-420,50	45	480,-420,45
480	-450	48	480,-450,48	45	480,-360,45
480	-480	48	480,-480,48	45	480,-480,45
480	-510	45	480,-510,45	45	480,-510,45
510	-100	41	510,-100,41	45	510,-100,45
510	-120	46	510,-120,46	45	510,-120,45
510	-150	54	510,-150,54	45	510,-150,45

510	-180	58	510,-180,58	45	510,-180,45
510	-210	56	510,-210,56	45	510,-210,45
510	-240	52	510,-240,52	45	510,-240,45
510	-270	50	510,-270,50	45	510,-270,45
510	-300	45	510,-300,45	45	510,-300,45
510	-330	37	510,-480,37	45	510,-480,45
510	-360	38	510,-510,38	45	510,-510,45
510	-390	40	510,-80,40	45	510,-390,45
510	-420	48	510,-90,48	45	510,-90,45
510	-450	44	510,-120,44	45	510,-120,45
510	-480	44	510,-150,44	45	510,-480,45
510	-510	46	510,-180,46	45	510,-180,45
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540	-90	40	540,-90,40	45	540,-90,45
540	-120	45	540,-120,45	45	540,-120,45
540	-150	55	540,-150,55	45	540,-150,45
540	-180	58	540,-180,58	45	540,-180,45
540	-210	55	540,-210,55	45	540,-210,45
540	-240	62	540,-240,62	45	540,-240,45
540	-270	54	540,-270,54	45	540,-270,45
540	-300	49	540,-300,49	45	540,-300,45
540	-330	39	540,-330,39	45	540,-330,45
540	-360	44	540,-360,44	45	540,-360,45
540	-390	42	540,-390,42	45	540,-390,45
540	-420	42	540,-420,42	45	540,-420,45
540	-450	44	540,-450,44	45	540,-450,45
540	-480	41	540,-480,41	45	540,-480,45
570	-60	40	570,-60,40	45	570,-60,45
570	-90	40	570,-90,40	45	570,-90,45
570	-120	42	570,-120,42	45	570,-120,45
570	-150	45	570,-150,45	45	570,-150,45
570	-180	51	570,-180,51	45	570,-180,45
570	-210	57	570,-210,57	45	570,-210,45
570	-240	55	570,-240,55	45	570,-240,45
570	-270	56	570,-270,56	45	570,-270,45
570	-300	44	570,-300,44	45	570,-300,45
570	-330	38	570,-330,38	45	570,-330,45
570	-360	32	570,-360,32	45	570,-360,45
570	-390	40	570,-390,40	45	570,-390,45
570	-420	44	570,-420,44	45	570,-420,45
570	-450	43	570,-450,43	45	570,-450,45
570	-480	40	570,-480,40	45	570,-480,45
600	-50	40	600,-50,40	45	600,-50,45
600	-60	42	600,-60,42	45	600,-60,45
600	-90	45	600,-90,45	45	600,-90,45
600	-120	43	600,-120,43	45	600,-120,45
600	-150	45	600,-150,45	45	600,-150,45

600	-180	47	600,-180,47	45	600,-180,45
600	-210	50	600,-210,50	45	600,-210,45
600	-240	43	600,-240,43	45	600,-240,45
600	-270	47	600,-270,47	45	600,-270,45
600	-300	40	600,-300,40	45	600,-300,45
600	-330	46	600,-330,46	45	600,-330,45
600	-360	43	600,-360,43	45	600,-360,45
600	-390	39	600,-390,39	45	600,-390,45
600	-420	40	600,-420,40	45	600,-420,45
600	-440	38	600,-440,38	45	600,-440,45
700	-30	38	700,-30,38	45	700,-30,45
700	-60	35	700,-60,35	45	700,-60,45
700	-90	35	700,-90,35	45	700,-90,45
700	-120	35	700,-120,35	45	700,-120,45
700	-150	44	700,-150,44	45	700,-150,45
700	-180	53	700,-180,53	45	700,-180,45
700	-210	41	700,-210,41	45	700,-210,45
700	-240	35	700,-240,35	45	700,-240,45
700	-270	36	700,-270,36	45	700,-270,45
700	-300	35	700,-300,35	45	700,-300,45
700	-330	40	700,-330,40	45	700,-330,45
700	-360	44	700,-360,44	45	700,-360,45
700	-390	35	700,-390,35	45	700,-390,45
800	-40	32	800,-40,32	45	800,-40,45
800	-60	34	800,-60,34	45	800,-60,45
800	-90	44	800,-90,44	45	800,-90,45
800	-120	41	800,-120,41	45	800,-120,45
800	-150	44	800,-150,44	45	800,-150,45
800	-180	42	800,-180,42	45	800,-180,45
800	-210	40	800,-210,40	45	800,-210,45
800	-240	35	800,-240,35	45	800,-240,45
800	-270	33	800,-270,33	45	800,-270,45
800	-300	40	800,-300,40	45	800,-300,45
800	-330	37	800,-330,37	45	800,-330,45
900	-90	34	900,-90,34	45	900,-90,45
900	-120	44	900,-120,44	45	900,-120,45
900	-150	43	900,-150,43	45	900,-150,45
900	-180	34	900,-180,34	45	900,-180,45
900	-210	32	900,-210,32	45	900,-210,45
900	-240	38	900,-240,38	45	900,-240,45
900	-270	40	900,-270,40	45	900,-270,45
900	-300	33	900,-300,33	45	900,-300,45
900	-330	46	900,-330,46	45	900,-330,45
900	-360	52	900,-360,52	45	900,-360,45
900	-390	52	900,-390,52	45	900,-390,45
1000	-160	30	1000,-160,30	45	1000,-160,45
1000	-180	38	1000,-180,38	45	1000,-180,45

1000	-210	31	1000,-210,31	45	1000,-210,45
1000	-240	34	1000,-240,34	45	1000,-240,45
1000	-270	38	1000,-270,38	45	1000,-270,45
1000	-300	35	1000,-300,35	45	1000,-300,45
1000	-330	38	1000,-330,38	45	1000,-330,45
1000	-360	53	1000,-360,53	45	1000,-360,45
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1000	-450	45	1000,-450,45	45	1000,-450,45
1100	-180	39	1100,-180,39	45	1100,-180,45
1100	-210	34	1100,-210,34	45	1100,-210,45
1100	-240	40	1100,-240,40	45	1100,-240,45
1100	-270	44	1100,-270,44	45	1100,-270,45
1100	-300	48	1100,-300,48	45	1100,-300,45
1100	-330	48	1100,-330,48	45	1100,-330,45
1100	-360	49	1100,-360,49	45	1100,-360,45
1100	-390	44	1100,-390,44	45	1100,-390,45
1100	-420	45	1100,-420,45	45	1100,-420,45
1100	-450	46	1100,-450,46	45	1100,-450,45
1100	-480	43	1100,-480,43	45	1100,-480,45
1100	-510	45	1100,-510,45	45	1100,-510,45
1200	-180	49	1200,-180,49	45	1200,-180,45
1200	-210	50	1200,-210,50	45	1200,-210,45
1200	-240	52	1200,-240,52	45	1200,-240,45
1200	-270	48	1200,-270,48	45	1200,-270,45
1200	-300	48	1200,-300,48	45	1200,-300,45
1200	-330	49	1200,-330,49	45	1200,-330,45
1200	-360	44	1200,-360,44	45	1200,-360,45
1200	-390	45	1200,-390,45	45	1200,-390,45
1200	-420	45	1200,-420,45	45	1200,-420,45
1200	-450	46	1200,-450,46	45	1200,-450,45
1200	-480	45	1200,-480,45	45	1200,-480,45
1200	-510	47	1200,-510,47	45	1200,-510,45
1300	-140	49	1300,-140,49	45	1300,-140,45
1300	-150	45	1300,-150,45	45	1300,-150,45
1300	-180	50	1300,-180,50	45	1300,-180,45
1300	-210	49	1300,-210,49	45	1300,-210,45
1300	-240	50	1300,-240,50	45	1300,-240,45
1300	-270	44	1300,-270,44	45	1300,-270,45
1300	-300	45	1300,-300,45	45	1300,-300,45
1300	-330	45	1300,-330,45	45	1300,-330,45
1300	-360	45	1300,-360,45	45	1300,-360,45
1300	-390	45	1300,-390,45	45	1300,-390,45
1300	-420	48	1300,-420,48	45	1300,-420,45
1300	-450	50	1300,-450,50	45	1300,-450,45
1300	-480	49	1300,-480,49	45	1300,-480,45
1300	-510	50	1300,-510,50	45	1300,-510,45

1400	-30	44	1400,-30,44	45	1400,-30,45
1400	-60	45	1400,-60,45	45	1400,-60,45
1400	-90	45	1400,-90,45	45	1400,-90,45
1400	-120	45	1400,-120,45	45	1400,-120,45
1400	-150	40	1400,-150,40	45	1400,-150,45
1400	-180	38	1400,-180,38	45	1400,-180,45
1400	-210	40	1400,-210,40	45	1400,-210,45
1400	-240	42	1400,-240,42	45	1400,-240,45
1400	-270	45	1400,-270,45	45	1400,-270,45
1400	-300	42	1400,-300,42	45	1400,-300,45
1400	-330	42	1400,-330,42	45	1400,-330,45
1400	-360	44	1400,-360,44	45	1400,-360,45
1400	-390	40	1400,-390,40	45	1400,-390,45
1400	-420	42	1400,-420,42	45	1400,-420,45
1400	-450	42	1400,-450,42	45	1400,-450,45
1400	-480	48	1400,-480,48	45	1400,-480,45
1400	-510	52	1400,-510,52	45	1400,-510,45
1500	-30	45	1500,-30,45	45	1500,-30,45
1500	-60	44	1500,-60,44	45	1500,-60,45
1500	-90	45	1500,-90,45	45	1500,-90,45
1500	-120	40	1500,-120,40	45	1500,-120,45
1500	-150	45	1500,-150,45	45	1500,-150,45
1500	-180	32	1500,-180,32	45	1500,-180,45
1500	-210	28	1500,-210,28	45	1500,-210,45
1500	-240	32	1500,-240,32	45	1500,-240,45
1500	-270	40	1500,-270,40	45	1500,-270,45
1500	-300	44	1500,-300,44	45	1500,-300,45
1500	-330	44	1500,-330,44	45	1500,-330,45
1500	-360	41	1500,-360,41	45	1500,-360,45
1500	-390	40	1500,-390,40	45	1500,-390,45
1500	-420	43	1500,-420,43	45	1500,-420,45
1500	-450	45	1500,-450,45	45	1500,-450,45
1500	-480	47	1500,-480,47	45	1500,-480,45
1500	-510	46	1500,-510,46	45	1500,-510,45
1600	-30	44	1600,-30,44	45	1600,-30,45
1600	-60	45	1600,-60,45	45	1600,-60,45
1600	-90	45	1600,-90,45	45	1600,-90,45
1600	-120	44	1600,-120,44	45	1600,-120,45
1600	-150	44	1600,-150,44	45	1600,-150,45
1600	-180	40	1600,-180,40	45	1600,-180,45
1600	-210	40	1600,-210,40	45	1600,-210,45
1600	-240	41	1600,-240,41	45	1600,-240,45
1600	-270	45	1600,-270,45	45	1600,-270,45
1600	-300	45	1600,-300,45	45	1600,-300,45
1600	-330	46	1600,-330,46	45	1600,-330,45
1600	-360	46	1600,-360,46	45	1600,-360,45
1600	-390	45	1600,-390,45	45	1600,-390,45

1600	-420	44	1600,-420,44	45	1600,-420,45
1600	-450	45	1600,-450,45	45	1600,-450,45
1600	-480	44	1600,-480,44	45	1600,-480,45
1600	-510	45	1600,-510,45	45	1600,-510,45
1700	-30	40	1700,-30,40	45	1700,-30,45
1700	-60	40	1700,-60,40	45	1700,-60,45
1700	-90	36	1700,-90,36	45	1700,-90,45
1700	-120	38	1700,-120,38	45	1700,-120,45
1700	-150	38	1700,-150,38	45	1700,-150,45
1700	-180	38	1700,-180,38	45	1700,-180,45
1700	-210	40	1700,-210,40	45	1700,-210,45
1700	-240	48	1700,-240,48	45	1700,-240,45
1700	-270	42	1700,-270,42	45	1700,-270,45
1700	-300	33	1700,-300,33	45	1700,-300,45
1700	-330	31	1700,-330,31	45	1700,-330,45
1700	-360	32	1700,-360,32	45	1700,-360,45
1700	-390	53	1700,-390,53	45	1700,-390,45
1700	-420	48	1700,-420,48	45	1700,-420,45
1700	-450	45	1700,-450,45	45	1700,-450,45
1700	-480	46	1700,-480,46	45	1700,-480,45
1700	-510	51	1700,-510,51	45	1700,-510,45
1800	-30	40	1800,-30,40	45	1800,-30,45
1800	-60	40	1800,-60,40	45	1800,-60,45
1800	-90	40	1800,-90,40	45	1800,-90,45
1800	-120	49	1800,-120,49	45	1800,-120,45
1800	-150	40	1800,-150,40	45	1800,-150,45
1800	-180	43	1800,-180,43	45	1800,-180,45
1800	-210	46	1800,-210,46	45	1800,-210,45
1800	-240	45	1800,-240,45	45	1800,-240,45
1800	-270	44	1800,-270,44	45	1800,-270,45
1800	-300	47	1800,-300,47	45	1800,-300,45
1800	-330	44	1800,-330,44	45	1800,-330,45
1800	-360	45	1800,-360,45	45	1800,-360,45
1800	-390	43	1800,-390,43	45	1800,-390,45
1800	-420	44	1800,-420,44	45	1800,-420,45
1800	-450	46	1800,-450,46	45	1800,-450,45
1800	-480	50	1800,-480,50	45	1800,-480,45
1800	-510	51	1800,-510,51	45	1800,-510,45
1900	-30	38	1900,-30,38	45	1900,-30,45
1900	-60	39	1900,-60,39	45	1900,-60,45
1900	-90	38	1900,-90,38	45	1900,-90,45
1900	-120	37	1900,-120,37	45	1900,-120,45
1900	-150	38	1900,-150,38	45	1900,-150,45
1900	-180	45	1900,-180,45	45	1900,-180,45
1900	-210	48	1900,-210,48	45	1900,-210,45
1900	-240	48	1900,-240,48	45	1900,-240,45
1900	-270	47	1900,-270,47	45	1900,-270,45

1900	-300	39	1900,-300,39	45	1900,-300,45
1900	-330	42	1900,-330,42	45	1900,-330,45
1900	-360	44	1900,-360,44	45	1900,-360,45
1900	-390	44	1900,-390,44	45	1900,-390,45
1900	-420	45	1900,-420,45	45	1900,-420,45
1900	-450	45	1900,-450,45	45	1900,-450,45
1900	-480	45	1900,-480,45	45	1900,-480,45
1900	-510	52	1900,-510,52	45	1900,-510,45
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1960	-60	42	1960,-60,42	45	1960,-60,45
1960	-90	40	1960,-90,40	45	1960,-90,45
1960	-120	44	1960,-120,44	45	1960,-120,45
1960	-150	48	1960,-150,48	45	1960,-150,45
1960	-180	45	1960,-180,45	45	1960,-180,45
1960	-210	49	1960,-210,49	45	1960,-210,45
1960	-240	52	1960,-240,52	45	1960,-240,45
1960	-270	49	1960,-270,49	45	1960,-270,45
1960	-300	46	1960,-300,46	45	1960,-300,45
1960	-330	44	1960,-330,44	45	1960,-330,45
1960	-360	41	1960,-360,41	45	1960,-360,45
1960	-390	45	1960,-390,45	45	1960,-390,45
1960	-420	44	1960,-420,44	45	1960,-420,45
1960	-450	44	1960,-450,44	45	1960,-450,45
1960	-480	40	1960,-480,40	45	1960,-480,45
1960	-510	46	1960,-510,46	45	1960,-510,45